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THE NEBULÆ IN THE VICINITY OF *NOVA PERSEI.*

By H. SEELIGER.

THE remarkable phenomena in the nebulæ near *Nova Persei*, the existence of which has been established by the photographs at the Heidelberg, Yerkes, and Lick observatories since the autumn of 1901, and which disclosed an apparent rapid motion, permit of the simplest explanation in the following well-known manner. At the time of its outburst there left the *Nova* a light-wave, powerful but decreasing in intensity comparatively quickly, which for a short time illuminated the surrounding cloud-structures, and, according to the measure of its progress, successively rendered visible new portions of the surroundings of the *Nova*. We designate these cloud-structures as nebulous, but without wishing to imply thereby anything as to their physical constitution. There can be no doubt that this exceedingly simple and obvious hypothesis, first published by Professor Kapteyn, is adequate for explaining all the essentials of the phenomena observed.

The photographs show, in addition to striking condensations and spots of light at different distances from the *Nova*, circular rings of light which are separated from each other by dark interspaces, and diffuse spots which are irregular and apparently of slight stability. This indicates that the material is not uniformly

distributed about the *Nova*, but that in many places it is arranged in flat layers and filamentary streaks; whereby of course only those portions of the matter can be taken into consideration which are sufficiently luminous to act upon the photographic plate. This is at least the simplest hypothesis. We could, indeed, also assume what to a limited degree would be certainly appropriate, that during the time of the greatest brilliancy of the *Nova* the light was not emitted equally in all directions. There would be in the neighborhood of the *Nova* absorbing accumulations which transmitted the light only in certain definite directions without weakening it too greatly. The *Nova* would also not have an equal luminosity at all the points of its surface, as we may assume *a priori*, and this may have caused a difference in the radiation in different directions which was quite independent of the time, to which we shall revert below.

The phenomena exhibited by the nebulæ in the neighborhood of the *Nova* are probably not yet at an end, and the observed data so far accumulated are not yet published in sufficient detail, so that it is not yet proper to undertake numerical computations. It appears to me, however, not to be inappropriate to discuss briefly the points of view as to principle which here come into question, since a lack of clearness on several points has become apparent. I therefore take the liberty of first treating the question as to what the observations indicate as to the form and the motion of the nebula in the neighborhood of the *Nova*, and what conclusions may be drawn therefrom. It will appear from this that the assumption that simple reflections are alone concerned is so general that an open contradiction of the observations could hardly be thought of.

Let us pass a rectangular system of coördinates through the *Nova* (N) as origin, with the X-axis in the direction of the very distant Sun, while the Y and Z-axes are perpendicular thereto. The light from N which falls upon the body, situated at a distance r, and is reflected by it to the Earth, will evidently require for its passage the time

$$\frac{1}{V}(r - x + \Delta),$$

where V is the velocity of light and Δ is the distance from the *Nova* to the Sun. If we disregard the insignificant variation in Δ, and compute the time t from the instant when the light from N reaches the Sun by the direct way, we have

$$r - x = \sqrt{x^2 + y^2 + z^2} - x = Vt = p \ . \qquad (1)$$

Now, if N was only for a short time, Δt, bright enough so that the reflected light could be sufficiently strong, then at the time t only those bodies would be visible in the neighborhood of the *Nova* which lie between the two paraboloids of revolution

$$r - x = Vt \quad \text{and} \quad r - x = V(t + \Delta t) \ .$$

$Vt = p$ is the parameter of the generating parabola, whose focus lies at N. Δt would probably amount to several days, since in this time the *Nova* declined several magnitudes in brightness.

If now a layer of nebular stratum, which therefore has a relatively small thickness and may be considered as having its mass distributed approximately in a plane, is illuminated by N, then at the time t those particles will appear upon the plate and form a curve which must lie near the intersection of the surface with the paraboloid. I will call this curve briefly the "observed curve." It will change its form and size with time, and we include all the data which can be yielded by the measurement of the plates if we assume that we fully know the equation of the observed curve

$$\phi\,(y, z, t) = 0 \ ,$$

or, solved for t,

$$t = f\,(y, z) \ . \qquad (2)$$

We must here assume that y and z are expressed in angular measure, say in seconds of arc. Further, y and z must also satisfy equation (1). Here x must be expressed on the same scale, therefore also in seconds of arc, but nothing is known as to V if the parallax π of the *Nova* is unknown. If π is expressed in seconds and the light equation of the Sun is $498^s.5$, we shall have

$$V = 63{,}300 = v\pi \ .$$

Hence for (1) we must write

$$\sqrt{x^2 + y^2 + z^2} - x = v\pi t \qquad (3)$$

We can now determine for each π the surface which is represented by the nebular layer, for it passes through the intersection of (3) and (2), the latter of which may be regarded as the equation of a right cylinder. The coördinates x, y and z of the required surface must, for every t, within a certain finite region, satisfy the equations (2) and (3). If we eliminate t from (2) and (3) we obtain as the equation of the required surface

$$\sqrt{x^2+y^2+z^2} - x - v\pi f(y, z) = 0 \ . \tag{4}$$

For every assumed value of π we can find the corresponding surface which represents the illuminated stratum of nebula. The parallax of the *Nova* therefore remains undetermined, and it is not determinable from measurements of the photographs which are before us without the aid of further and quite arbitrary hypotheses.

Kapteyn[1] assumes that the observed curves are circles whose centers do not coincide with N. This assumption agrees very well with the outer nebulous streaks according to photographs at the Yerkes Observatory, particularly toward the west and toward the southwest on the plate of September 20th, 1901, and also fairly well toward the north on the plates taken in January and February, 1902. He adds further that the distance ζ of the center of the circle from N changes proportionately to the time without change of direction, and similarly for the radius of the circle R. These assumptions do not seem to me to be very well founded, judging by the copies of the plates accessible to me, but nevertheless this assumption will not be further discussed, and we shall merely draw the inferences that follow from it.

If we place

$$\zeta = ct \ , \quad R = \gamma t \ ,$$

the equation of the apparent curve becomes

$$y^2 + (r - ct)^2 = \gamma t^2 \tag{5}$$

and, after some easy reductions, the equation of the required surface is found to be

$$(m^2 - n^2)(y^2 + z^2) + 4 \{xznc(m^2 + n^2) - c^2n^2z^2 - m^2n^2x^2\} = 0 \ ,$$

[1] *A. N.*, 157, 201, 1901.

where for brevity we have placed

$$m^2 = \gamma^2 - c^2 \quad \text{and} \quad n = v\pi \ .$$

This equation represents a right cone whose vertex is at *N*. Its axis lies in the *XZ* plane, making with the *X* axis an angle α, which is determined by

$$\sin \alpha = \frac{2cn}{\sqrt{(m^2 + n^2)^2 + 4c^2n^2}} \ ; \quad \cos \alpha = \frac{m^2 + n^2}{\sqrt{(m^2 + n^2)^2 + 4c^2n^2}} \ ;$$

$$\tan \alpha = \frac{2cv\pi}{\gamma^2 - c^2 + v^2\pi^2} \ .$$

The angle f between a light-ray of the cone and its axis is found to be

$$\tan f = \frac{2\gamma v}{\gamma^2 - c^2 - v^2\pi^2} \ .$$

These results are all that can be obtained with certainty from any measurements; the parallax π of the *Nova* remains wholly undetermined.

Kapteyn's assumption corresponds to $f = 90°$, and is equivalent to the entirely arbitrary assumption

$$v\pi = \sqrt{\gamma^2 - c^2} \ .$$

If the observed curves do not satisfy equation (5), another surface of course at once takes the place of the cone. We remark incidentally that the result could also be otherwise interpreted in case the definitive measurement of the plates actually led to conical surfaces of the kind above mentioned. If the outburst of the *Nova* was produced by the entrance of a dark celestial body into a cosmical cloud, then the amount of heat generated would by no means be equal for all points of the surface; but it would be the greatest where the principal resistance was encountered, and would decrease in all directions from there. We might accordingly ultimately picture the situation in this way: the light reflected from the neighborhood of the *Nova* came from a certain polar zone inasmuch as the light proceeding from the other parts of the surface of the *Nova* was too faint to be noticed. The body of the *Nova* would therefore produce something like a shadow cone, and if the intersection of this cone with the paraboloid was occupied by particles sufficiently reflect-

ing the light, the observed curve (5) would result. We are here only mentioning one of the possibilities at hand, without investigating its greater or less probability. If we seek to explain in this way the most remote parts of the nebula in the west and southwest, and later in the north, it follows that the brightest parts of the *Nova* lay on the side away from the Sun. Under certain assumptions this would further lead us to infer that the relative motion of the *Nova* with respect to the nebula was as if the *Nova* was receding from the Sun and the nebula approaching.

Let us now consider a streak of nebulosity, a body of essentially linear extent.

The projection of the intersection of the wisp with the paraboloid will appear illuminated at the time t, and will look like a bright spot. Such a bright spot will move further along the projection of the wisp, and the measurement of the plate will yield equations of the form

$$\left.\begin{aligned} y &= \phi(t) \\ z &= \psi(t) \end{aligned}\right\} . \tag{6}$$

The x coördinate of this point will follow, as before, from the equation of the paraboloid,

$$\sqrt{x^2 + y^2 + z^2} - x = v\pi t \ ,$$

and will be

$$x = \frac{y^2 + z^2 - v^2\pi^2 t^2}{2\,v\pi t} \ . \tag{7}$$

Equations (6) and (7) represent the equations of the wisp of nebula in terms of the parameter t, and a definite and always real value of x belongs to every value of π. In this case π is therefore again wholly indeterminate. It is hardly necessary to remark that the moving bright spot will retain almost the same form if the mass is distributed homogeneously along the wisp; otherwise its form must change.

These remarks doubtless suffice to show that one cannot doubt that there are possibilities enough available for explaining all the phenomena in the vicinity of the *Nova*. For the present nothing further is intended to be presented by this discussion.

Dr. Louis Bell has recently expressed the opinion[1] that there

[1] ASTROPHYSICAL JOURNAL, **16**, 38, 1902.

are difficulties in the way of the simple reflection theory, which are partly of a physical nature. He therefore gave preference to the view that the effects about the *Nova* are not purely optical, but are principally electrical actions, which however must follow the same geometrical laws. Mr. Bell brings forward three points which I should now like to discuss.

"First, reflected light, whether reflected in the ordinary way from heterogeneous surfaces or from small particles, would be polarized, and Perrine's report on this feature of the case indicates absence of polarization." To this we would remark as follows: Up to the present no details have been published as to Perrine's experiments. It is well known that it is generally a very difficult matter to prove the existence of polarized light from cosmical bodies, even in cases where there can be no doubt as to the presence of partial polarization. The following facts may be recalled.

According to Secchi[1] and others the full Moon exhibits no polarization, but with increasing phase-angle it becomes demonstrable, and reaches a maximum in the first and last quarters. At this time it is nearly uniformly distributed over the entire lunar surface, but its amount is decidedly dependent upon the nature of the surface. Polarized light has indeed never been detected on the lunar mountains, while the *maria* exhibit comparatively strong polarization. Great difficulties are met with in analogous investigations of the planets, and I am not familiar with any numerical results. Although the heads of comets show polarized light, it is in very small quantity. In a head of Coggia's comet (1874) Zenker[2] was able to detect it, but he could not determine its percentage. He says "the polarization was certainly very slight, but nevertheless I did not estimate it to be any greater in the case of *Jupiter*." The question as to the emission of polarized light by the zodiacal light was a matter of controversy for several decades, the individual results being decidedly diverse, sometimes entirely negative and sometimes indicating faint polarization. A certain conclusion was brought to the question by the work of A. W. Wright,[3] who found: (1) That the zodiacal light is polarized in a plane passing through the Sun;

[1] *A. N.*, **52**, 93, 1860. [2] *A. N.*, **84**, 173, 1874. [3] *Am. Jour.* (3) **8**, 39, 1874.

(2) that the amount is probably 15, but scarcely 20 per cent. Ordinary clouds, as is well known, exhibit no polarization, but the light of the blue sky exhibits it in a high degree—at points 90 degrees from the Sun amounting under some circumstances to 88 per cent. In this respect the matter has been very accurately studied and the facts established.[1] Terrestrial objects giving diffuse reflection obviously can be much more readily and accurately investigated in respect to polarization, and a considerable number of experiments of this sort are available. A. W. Wright investigated a number of rocks, and he found between 5 and 26 per cent. of polarized light present; *e. g.*, for common dust 15.5, for syenite 16.4, for gneiss 8.3, for granite 11.8, for sandstone 12.1, for meteorites 11.7 per cent., etc. Finely divided powder was also studied by Henry Wright,[2] who found that no trace of polarization could be proven to be present.

The state of the case seems to be, as is of itself plausible, that a great quantity of discrete particles exhibit no demonstrable polarization as long as the dimensions of the particles are appreciably greater than the wave-length of light, and a certain irregularity in shape seems to be favorable for the absence of polarization. So-called turbid media (blue sky acts as such) consist of such small particles, compared with which the wave-length of light is not small, and therefore the light reflected from them may under some circumstances be strongly polarized.

In this state of affairs and in view of the great difficulties attending the analysis of a source of light so exceedingly faint as that of the nebula near *Nova Persei*, we should expect in advance a negative result from the experiments of Mr. Perrine; the result obtained could therefore be hardly surprising, as we ought to expect that the nebula would act in a similar manner to the turbid media. If the experiments of Mr. Perrine require us to exclude this possibility, it would naturally be a very interesting result, but without special importance for the question in hand. We are absolutely unable to judge of the accuracy or

[1] See the summary by JENSEN, *Meteor. Zeitschrift*, **18**, 547, 1901.

[2] "Die diffuse Reflexion des Lichtes an matten Oberflächen," *Münchener* Doctor dissertation, 1899, and *Ann. der Phys.*, **1**, 17, 1900.

inaccuracy of the result found on the basis of the investigations published. But even if it was not permissible to raise such doubts, the position with respect to the *Nova* of the portions of the nebula investigated would have to be taken into account; for the blue sky itself does not exhibit strongly polarized light at all distances from the Sun.

The second objection of Mr. Bell is this: "Second, reflection does not adequately explain the very remarkable persistence of some regions of strong nebulosity at a small angular distance from the *Nova*. Especially the nebular peak nearly south of the *Nova* has an intensity all out of proportion to that of the outer ring, while both on the reflection hypothesis should be at similar radial distances. If they are, then the ring must represent a condition of matter having a very small albedo compared with that in the other region."

These remarks seem to be based upon a misunderstanding. The surface brightness of a portion of the nebula is dependent upon the density, the distribution of matter, and the albedo of the particles at the place in question, and on the absorption which the light from the portion of the nebula suffers on its way to the Sun, on the phase-angle and on the distance from the source of light. The very bright spot already mentioned is situated at a very small angular distance from the *Nova*, and it must, according to our foregoing considerations, lie on the side of the *Nova* away from the Sun and not far from our line of sight through the *Nova*. In other words, since the spot lies on the paraboloid, its parabolic true anomaly α must be very small. If we compare the surface brightness h in this spot with that of a portion of the outer ring, for which let the true anomaly be α_1, and if we notice that the phase-angles in the two cases are similarly α and α_1, and if $f(\alpha)$ represents the dependence of the brightness on the phase-angle, then, other things being equal, we shall have

$$\frac{h}{h_1} = \frac{f(\alpha)}{f(\alpha_1)} \left(\frac{\cos \frac{1}{2} \alpha}{\cos \frac{1}{2} \alpha_1} \right)^4 .$$

$f(a)$ decreases quite considerably with increasing a, and similarly the second factor is much greater than 1. We may place $\cos \frac{1}{2}a = 1$, while a may be much greater than $90°$, for the outermost ring perhaps $120°$. On this assumption the second factor becomes 16, so that $\frac{h}{h_1}$ may easily be several digits, even on only moderately favorable assumptions. Mr. Bell's assumption "should be at similar radial distances," therefore rests upon an oversight. Quite aside from the possibility of the free choice of the density, of the albedo, or of suitable conditions of absorption, we can understand why just these spots in the immediate vicinity of the *Nova* are particularly bright.

The third and last objection of Mr. Bell is this: "Third, at the radius of 210 light-days denoted by the ring of September 20, reflection does not adequately account for the brightness of the nebular matter observed," etc.

In respect to this I base my view on one of my papers which was published several months before the discovery of the nebula near the *Nova*, and upon my note in *Astronomische Nachrichten*, where I reach results different from those of Mr. Bell. It is probably unnecessary to discuss the matter anew here. It needs only to be remarked that in the choice of the albedo values of the particles constituting the nebula, of the density of the distribution of the mass, and of the thickness of the reflecting layers, we have at hand a means of determining the absorption produced by any superposed masses of nebula to correspond to the observations, as easily follows from the formula which I have elsewhere given. There is no necessity of making any *a priori* assumptions as to the albedo, since we know absolutely nothing as to the physical nature of the matter in the vicinity of the *Nova*. We must abstain from making a comparison with the residual particles of gas in exhausted Geissler or Hittorf tubes, not only because of the considerably different conditions of pressure in spite of the greatest exhaustions attained, but also, and especially, on account of the extremely low temperature which small cosmical masses must have in empty space, which are not to be compared with those under which laboratory experiments have

hitherto been conducted. For the present, therefore, the application of the results of laboratory experiments for explaining the phenomena of the nebula near *Nova Persei* has scarcely more justification than the invocation of a whole series of vague hypotheses. In my view we certainly should not decide to employ such hypotheses before the reflection theory has been entirely shipwrecked. For this reason I do not wish to enter into a more detailed discussion of the views expressed by Mr. Bell.

MÜNCHEN, October 1, 1902.

THE MOVEMENTS IN THE NEBULA SURROUNDING *NOVA PERSEI.*

By ARTHUR R. HINKS.

IT seems to be quite certain that the apparent velocities in the nebula surrounding *Nova Persei* are of the order of the velocity of light; they can hardly be much less, and it is perhaps scarcely necessary at present to worry about how to explain them if they should be greater.

Assuming then, for the moment, that we are concerned with a velocity equal to that of light, we have to decide between two possibilities. Either the structures which appear in motion are material ejected from the star with the velocity of light, and continuing to move without any very apparent acceleration or retardation; or they are due to the lighting up of successive parts of a nebula already in position around the stars, by some influence proceeding outward with the velocity of light. It is with one or two aspects of the latter possibility that this note is concerned.

Various suggestions have been made as to the nature of the influence proceeding from the star which might develop an already existing nebula in the fashion which has been observed. Simple reflection, luminosity excited in tenuous gas by an electromagnetic wave, luminosity due to the recombination of tenuous gas after dissociation by a light-wave passing through it, luminosity following bombardment by streams of projected ions, have all been suggested. It was pointed out in a discussion at the recent meeting of the British Association in Belfast that they all come to practically the same thing. They are all concerned with the lighting up of an already existing distribution of matter by an influence traveling outward with the velocity of light. In any case the resulting apparent structure would be much the same, and we need not try to discriminate between the various suggestions as to the exact nature of the physics involved, until

we are satisfied that the "lighting up" hypothesis is competent to explain things generally.

It has been alleged against the lighting-up hypothesis that it will not explain the persistence of certain definite forms, the cusps or arrow heads, which are the most striking features of the moving nebula. It seems to me, however, that if one follows out in detail a case of "lighting-up" one finds that no such difficulty occurs. Kapteyn remarks that all points of the nebula which light up simultaneously as the result of an instantaneous burst of light lie on the surface of an ellipsoid of revolution, whose foci are at the star and the Earth. We may treat the portion of the ellipsoid near the star as a paraboloid; and it is easy to see that the retardation, that is, the interval between the arrival at the Earth of light which has come direct and the arrival of light which has come *via* a point on the paraboloid, is equal to the time which light takes to traverse the semi-latus-rectum of the paraboloid. If then light travels from the star at S in a direction which makes an angle ϕ with the line SE to the Earth, and lights up a point P at a distance R light-years from S, the "retardation" of the lighting up of P is the length in light-years of the semi-latus-rectum of the parabola through P, with S as focus and SE as axis; and that is $R\ (1-\cos\phi)$.

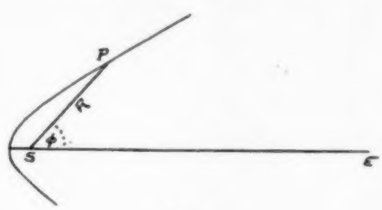


FIG. 1.

Now imagine that nebulous matter is disposed in a circle with the star as center, with a radius of R light-years, and that the plane of the circle makes an angle θ with the line of sight. Different radii of this circle will make angles ϕ with this line, which lie between θ and $\pi-\theta$; and corresponding points on the circle will appear successively with retardations lying between $R\ (1-\cos\theta)$ and $R\ (1+\cos\theta)$ light-years. Take a particular case. Suppose $\theta=30^\circ$ and $R=3.73$ light-years (so that $R\ (1-\cos\theta)$ is equal to half a year.) The circle viewed from the earth will be projected into an ellipse. If ψ is the angular distance on the circle between any point P and the point of the

ring nearest the Earth, which projects into an end of the minor axis, then ϕ is found for the point P from the relation $\cos \phi = \cos \theta \cos \psi$. Taking points at equal intervals of 20° round the circle we have the following table:

$\theta = 30°$ $R = 3.73$ light-years.

ψ	$1 - \cos \psi \cos \theta$	Retardation
0°	0.134	0.50 years
20	0.186	0.69
40	0.337	1.26
60	0.567	2.12
80	0.849	3.17
100	1.151	4.29
120	1.433	5.35
140	1.663	6.20
160	1.814	6.77
180	1.866	6.96

It follows that if the star lights up for an instant we shall have this sequence of events. Six months afterward a point of nebulosity will appear at B. This will divide into two points which travel round the ellipse in opposite directions, at first rapidly, then slowing as they approach the ends of the major axis, and finally quickening as they come together again after six and a half years at the end of the minor axis opposite B.

Proceeding now to the case of a sudden outburst of light which dies away gradually. Our points become lines, which move round the ellipse as before; they are brightest at the head, and fall off in intensity as the star fell off. This is the result for a narrow circular distribution of nebula. But suppose now that the nebular ring has some breadth in the plane of the circle; and consider it divided into a number of narrow concentric elements. Each element will contribute a pair of moving lines as above; and further, as we go outward the head of each successive elementary line will be set a little back from the one that precedes it, since its light-radius R, and consequently its retardation, is slightly greater. We shall therefore get as an aggregate effect two moving cusps or arrow-heads as in Fig. 3.

It seems that the lighting-up hypothesis is competent to explain how two cusps of nebulosity may appear to move in

opposite directions and retain their form. Some such effect will be produced by the lighting up of any wisp of nebula, and I am far from suggesting that the examination of our simple example, the flat circular ring, goes any way toward discovering what is the real form of the *Nova Persei* nebula. It can do no more than point out how immensely the retardation complicates the effect of a light explosion among wisps of nebulosity. For instance, if we assume that our flat circular ring has a breadth of half a light-year, it is easy to show that the history of the moving cusps which result from it is given briefly in Fig. 4.

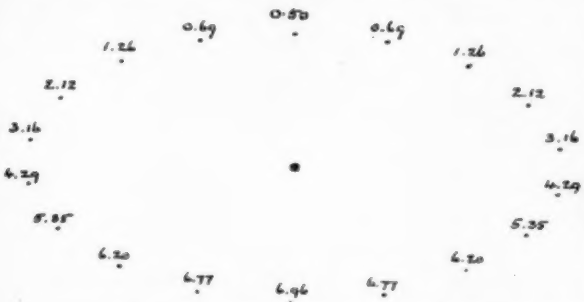


FIG. 2.—Retardation, in years, of light reflected from successive points, 20° apart, round a circular ring, about *Nova* as center, inclined 30° to the line of sight, and of radius 3.73 light-years.

The cusps start by being sharp; become blunted as they approach the apsides of the ellipse; and finally become more and more acute as they draw together again.

The early stages are not altogether unlike those shown in Ritchey's drawings of 1901, September 20, and 1902, February 8, for the condensations lettered *a* and *e*, which moved during that interval from the positions shown in black to the positions shown in outline in Fig. 5.

FIG. 3.

These quick-moving cusps of light were probably formed in a wisp of nebula that lay well on our side of the star, since they lit up very soon after the direct light of the star reached us, although they are at a considerable angular distance from it. It is perhaps more likely than not that these wisps are disposed all

round the star in spirals or other curves; and if this is so, it is not impossible that we may see things gradually develop something after the fashion of our example; that we may see the cusps which are now separating on one side of the star come together again on the other. And if such things have happened round other *Novæ*, it is perhaps not even now too late to photograph them in their last stages.

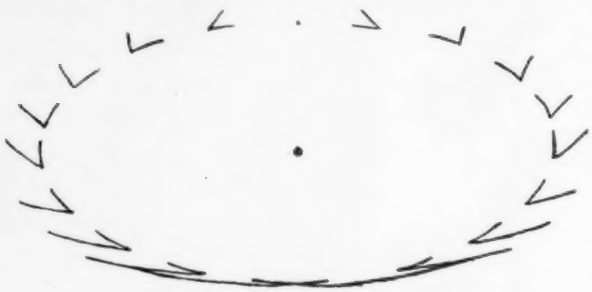


FIG. 4.

It is very easy, with this lighting-up hypothesis, to work out what will happen for a particular distribution of nebula. Probably it would be very troublesome to work back from a set of observed appearances, and make out the distribution of nebula which might have given rise to them. At any rate the time for that is not yet. But I should like to suggest that, if anything is to be made of the problem, a knowledge of all the outlines of the nebula will be at least as necessary as knowledge of the positions and movements of certain defined and measurable points; and that probably nothing could be better for this purpose than more drawings from photographs, made very carefully to scale, after the fashion of Mr. Ritchey's admirable drawings which have already appeared in the ASTROPHYSICAL JOURNAL.

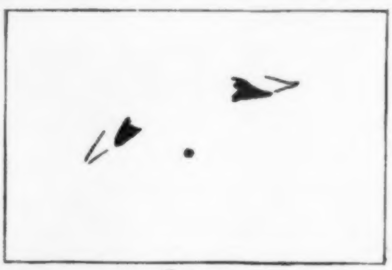


FIG. 5.

CAMBRIDGE OBSERVATORY, ENGLAND,
September 24, 1902.

MINIMUM SUN-SPOTS AND TERRESTRIAL MAGNETISM.

By A. L. Cortie, S.J.

The relation which exists between the diurnal range of magnetic declination and horizontal force and the period of solar spot frequency has been fully discussed by Mr. Ellis for the period 1841–1896 by means of the Greenwich magnetic curves and the tables of Sun-spot frequency prepared by Dr. Rudolf Wolf. (*Proc. R. S.*, **63**, 64). The author sums up the results of his study of the subject as follows: "Considering that the irregularities in the length of the Sun-spot period are so entirely synchronous with similar irregularities in the magnetic period, and also that the elevation or depression of the maximum points of the Sun-spot curve is accompanied by similar elevations and depressions of the two magnetic curves, it would seem, in the face of such evidence, that the supposition that such agreement is probably only accidental coincidence can scarcely be maintained, and there would appear to be no escape from the conclusion that such close correspondence, both in period and activity, indicates a more or less direct relation between the two phenomena, or otherwise the existence of some common cause producing both." Moreover, the discussion showed that the strict relation as to intensity and duration of the periods was almost identical, whether the curves of magnetic diurnal range were derived from quiet days only or from all days, quiet or disturbed. That this relation between the two phenomena cannot be one of efficient cause and effect has been theoretically proved by Lord Kelvin, and observationally by Father Sidgreaves. In his paper on the "Connexion between Solar Spots and Earth-Magnetic Storms" (*Memoirs R. A. S.*, **54**), Father Sidgreaves classified and studied all the magnetic storms and all the greater solar spots for the years 1881–1896. The tables which illustrate the paper show that years of greater solar activity are accompanied by greater magnetic storms, while in years of solar minimum there are but few storms.

These facts demonstrate the close connection that exists between solar and magnetic storms, in addition to and beyond the consonant mean periodic fluctuation of the two phenomena established by Mr. Ellis. But on the other hand, in every class of solar spot magnitude there was at least one spot unaccompanied by a corresponding magnetic storm, and besides, there were correlatively great magnetic storms which occurred during periods of absolute solar quiet. These results are adverse to any theory which would place the cause of magnetic storms, and by the cause we mean the efficient cause, anywhere on or in the vicinity of the Sun. Father Sidgreaves proposes a theory according to which streams of electrified corpuscles moving with high velocity in interplanetary space would act sometimes as the hot vapors issuing from the photosphere, darkening them electrostatically, and sometimes on the Earth magnetically, and when the corpuscles were very numerous on both Sun and Earth. But though solar spots and their allied phenomena of faculæ and prominences are not the efficient cause of magnetic storms on Earth, may they not be a primary instrumental cause? This position appears to be that taken up by Professor Young in the latest edition of his work, *The Sun*, where he likens the action of the spot to the pulling of a trigger which causes the flight of the rifle-bullet, inasmuch as it releases the potential energy stored up in the powder, and causes the explosion which ensues. A similar action would be that by which the pressing of a button causes the launching of the huge mass of metal contained in the hull of a warship. Sometimes the trigger is pulled but the expected explosion does not occur, owing to some casual defect, and so, too, analogously the solar spot may appear, but no answering magnetic storm occurs. As examples of the direct action of solar storms on terrestrial magnetism, Professor Young gives in his book two instances which occurred on August 3 and 5, 1872, in which striking and extraordinary reversals of the C line, *Ha*, in a solar spot were exactly coincident in time with movements in the magnets. But with all deference to the opinion of so eminent a solar observer as Professor Young, the magnetic curves do not appear to warrant anything more than the deduction of a mere coincidence in time

between the chief paroxysms of the solar *Ha* reversals and the corresponding swings of the magnets. If the magnetic movements at these times had occurred during an otherwise magnetically calm day, the evidence of cause and effect would have been very weighty, but the oscillations of the magnets observed at the stated times are neither peculiar nor unusual during the course of magnetic storms. The second instance given, that of August 5, is stronger than the first, but even here the coincidences occurred at the tag-end of the magnetic storm which had run its course during the two preceding days. There was undoubtedly a general connection between the two phenomena, but, at least in the opinion of the writer, not the intimate connection claimed.

But to return to the general question as to the kind of connection that obtains between Sun-spots and terrestrial magnetism. If the solar spot be the primary instrumental cause in the production of a magnetic storm, its action ought not to be frustrated in a great number of cases, nor ought it to act capriciously and without method as to the order of the occurrence of the two phenomena, or to the time, before the reputed cause works its effect. A spot of any large area ought to be accompanied by a bigger magnetic movement, and it ought reasonably to be expected that it should occur when the spot was most active. It seemed possible to derive some further knowledge of the mode of action of the Sun-spots and faculæ by instituting a detailed comparative study of the solar surface and magnetic curves, and not merely a comparison of means for long periods, in which the principle of compensation is apt to mask the individual departures from the mean values. Moreover, if a period of minimum solar spots and magnetic storms were selected for study it would be more possible to determine the connection, if any, between the spots that appeared and any abnormal ranges in the magnetic elements. For though such ranges might be comparatively small at times of great disturbance, they would be very noticeable at periods of calm. Again, at periods of maximum solar and magnetic activity the storms are so mixed up the one with the other that it becomes a difficult matter to assign individual magnetic disturbances to their solar concomitants.

Such a discussion, even if it did not do much to elucidate the matter, might serve to corroborate past results from more recent observations. Accordingly, the three years, 1899–1901 inclusively, were selected, the material for the study of the solar surface being the Stonyhurst drawings supplemented by a very careful series of eye observations by Mr. Hadden, of Alta, Ia. For the magnetic disturbances the Stonyhurst series of curves for the declination elements were taken as sufficient for the purposes of comparison. The character of the movements for each day for the three elements is also given in the Stonyhurst annual reports. In addition the mean daily disk areas of the spots and faculæ, expressed in millionths of the Sun's apparent disk, were taken for the thirty-eight solar rotations covering the period from the results published in the *Monthly Notices R. A. S.* **61**, Nos. 1 and 8, and **62**, No. 5. These form the third and fourth columns of the annexed table, the fifth and sixth columns showing the mean diurnal range of the declination magnet for each corresponding rotation, and the greatest diurnal range during the rotation.

The general connection between the state of the solar surface and the intensity of the magnetic declination for the three years is well shown in the Stonyhurst annual reports. The mean daily disk areas of the spots reckoned in terms of the $\frac{1}{5000}$ of the apparent disk are 0.74, 0.55, and 0.29, with the corresponding mean diurnal ranges 12!9, 9!7, and 9!1. We may remark that there is not such a marked decline in the magnetic as in the solar disk area for the two years 1900 and 1901, though the general decline affects both. But when the individual solar rotations from which the average results are drawn are studied, the existence of great anomalies is detected, as the following table will show.

The lack of perfect accord in the majority of cases is still more apparent when the daily solar observations are compared with the daily readings of the magnetic curves. In the year 1899 there were seven days on which the magnetic disturbances were classed as relatively great, in the year 1900 two, and none at all in the year 1901. The first greater movement of the magnetic needles for 1899 occurred on January 28, when there were some

Rotation		Greenwich		Stonyhurst	
		Mean of daily disk area		Mean of magnetic diurnal range	
Number	Begins	Spots	Faculæ		Greatest range
606	1899 Jan. 15	271	399	10.3	32.0
607	Feb. 11	154	402	15.5	28.7
608	March 10	38	218	16.2	37.5
609	April 7	485	441	15.4	29.6
610	May 4	159	344	14.7	37.5
611	May 31	61	211	12.7	20.5
612	June 27	173	410	15.6	65.0
613	July 24	448	439	12.6	21.5
614	Aug. 21	21	345	12.4	18.6
615	Sept. 17	3	161	12.8	23.5
616	Oct. 14	54	160	11.7	45.0
617	Nov. 10	129	152	9.9	25.0
618	Dec. 8	67	233	9.1	17.0
619	1900 Jan. 4	99	161	12.4	36.0
620	Jan. 31	133	327	9.2	30.5
621	Feb. 28	155	215	12.2	40.0
622	March 27	124	221	10.8	17.0
623	April 23	253	312	11.7	52.0
624	May 21	91	241	10.5	14.0
625	June 17	163	104	10.4	14.0
626	July 14	58	126	10.6	16.5
627	Aug. 10	28	36	11.9	20.0
628	Sept. 6	21	95	8.7	14.5
629	Oct. 4	210	88	9.1	19.3
630	Oct. 31	18	66	5.9	10.5
631	Nov. 27	0	14	4.2	8.2
632	Dec. 25	1	0	7.3	18.0
633	1901 Jan. 21	8	13	6.9	19.0
634	Feb. 17	22	29	8.5	26.0
635	March 17	0	7	11.4	28.0
636	April 13	0	0	10.4	19.3
637	May 10	339	53	11.8	40.0
638	June 6	70	34	10.7	20.0
639	July 4	1	47	10.8	16.0
640	July 31	0	6	11.1	28.0
641	Aug. 27	0	2	10.3	30.5
642	Sept. 23	10	8	9.0	24.0
643	Oct. 21	29	94	7.0	13.0
644	Nov. 17	51	4	5.0	12.0

small spots on the Sun. If this be reckoned as a possible connection, the second greater movements of February 12 cannot be so, as they took place when the solar surface was perfectly quiet. The two chief solar outbursts of the year occurred during March and June; the first consisting of a spot visible during one rotation from March 15 to March 27, and the second of a spot

formed on the invisible side of the Sun, which crossed the visible disk but once, also between June 23 and July 5. Two days of greater disturbance (March 21 and 23) accompanied the one spot when it had attained its greatest disk-area, and two others also (June 28 and 29) the second spot when it too passed the central meridian, after many reversals of the *Ha* line had been observed in it two days previously. The greatest range of the year of the declination magnet took place on the 29th. Between these two periods of solar activity a quiet time intervened in April and May. However, a few unimportant spots were on the Sun in the latter half of April and the first days of May, that might be possibly claimed as coincident with the magnetic storm and accompanying aurora of May 3. We have, therefore, of seven days of greater magnetic disturbance during the year, four coincident with greater spot-area, two possibly coincident with small spots, and one case of non-coincidence. After the middle of July the spots and faculæ became very scarce and small, with a quite remarkable absence of bright faculæ during August. After this period of calm the Sun's surface began again to be disturbed about the 20th of September, and during this period some moderate disturbances of the magnets and a corresponding aurora on the 26th were experienced. There had, however, been just such similar movements during August when the Sun was quite calm. Again in October a moderate sized spot with bright faculæ in which reversals of the *Ha* line were observed, was seen on the east limb of the Sun on the 23d, which was accompanied by a moderate disturbance with an extreme range of 45′, the second greatest swing of the year. But in December, when there was quite a small recrudescence of solar activity after another period of calm, in which there was a moderate disturbance of the magnets of similar character to that of October, with nothing on the Sun, the magnets were not only undisturbed, but were at the quietest period for the whole year. In January 1900, there were six moderate movements of the magnets, that of the 21st being accompanied by an aurora. All these, except the last, which was coincident with the appearance of a new spot, occurred during a period of calm. The only

moderate swing of February was coincident with a few spots of small area. These moderately large movements of the magnets, therefore, throw no light on the subject under discussion, except that they occur equally with and without spots. Their origin may be purely terrestrial.

The first great storm of the year 1900 occurred on March 13. A fine group of spots characterized by spectroscopic *Ha* reversals, had appeared about two days' distance west of the central meridian on March 6, and passed off the visible disk on the 11th. It was possibly still active on the 13th, when on the invisible hemisphere of the Sun. During the intervals March 26–April 17, and April 27–May 6, the solar surface was fairly active but the magnets were calm, with the exceptions of the dates May 4 and 5, when moderate and great storms were recorded as one group was passing round the west limb. An aurora was observed on May 1. This was the second greater disturbance of the year. Both, though recorded during an active solar period, do not seem to have any very close connection, either with the position of the spots on the Sun's disk, or with their more active phases.

Although in the year 1901 there was no magnetic disturbance that can be classed as great, yet there was a very fine spot on the Sun visible to the unaided eye, which lasted for nearly two solar rotations, and in its two appearances on the visible disk, contributed no less than 74 per cent. of the total spotted area for the year. It was, very probably, born just off the east limb of the Sun on the very day of the total eclipse, May 18, and its presence was marked by a coincident fine prominence, and by a disturbed area of hitherto unobserved character in the solar corona. The spot outburst had been prepared for by an appearence of bright faculæ in the very position in which it subsequently broke out, a whole rotation previously. There was no magnetic disturbance of any moment during either of this spot's transits across the visible hemisphere. The greatest magnetic oscillation of the year, however, occurred on May 10, coincident with a possible short-lived spot on the invisible hemisphere of the Sun, but when the visible disk was absolutely

calm, and fully seven days before the outbreak of the one great solar spot group of the year. When the spot was most active the magnets were absolutely quiet. In fact, as the table shows, between March and August, including the rotations 635 to 641, the mean diurnal range was almost constant, while the mean daily disk-area of the spots was fluctuating between 0 and 339 units. A full discussion of this spot group was given in the *Monthly Notices R. A. S.*, **62,** No. 7, and the conclusion there stated was that "the one great solar disturbance of the year, which showed itself in a spot visible to the naked eye, in a fine prominence, in bright faculæ, and in an unique coronal disturbance, was unaccompanied by any considerable magnetic storm, and seemingly had but a fortuitous connection with the slight and moderate disturbances which occurred during its existence."

The minimum of solar activity has persisted during the six months that have elapsed of the present year, the only spot of any size crossing the disk between March 5 and 13, unaccompanied by any striking magnetic disturbance. From this date to May 19 the Sun was absolutely clear of spots, and what faculæ there were, were very faint and unimportant. Yet on April 10 there was a magnetic disturbance which was relatively great, with a maximum swing of the declination needle of 38′.4, and in general character more intense than the short lived disturbances of May 10, 1901. These two cases, the one of a fine spot without any magnetic disturbance, and the other of the greatest magnetic disturbance of the six months without any accompanying spot at all, are sufficient of themselves to disprove any intimate connection of cause and effect between the two phenomena. Yet it may be possible, judging from the above detailed discussion of the minimum period, that Sun-spots are one of the instrumental causes of magnetic storms, though not the only one, but it is more likely that the two phenomena are correlated as two connected, though sometimes independent, effects of one common cause.

STONYHURST COLLEGE OBSERVATORY,
July 26, 1902.

SOLAR RESEARCH AT THE YERKES OBSERVATORY.

By George E. Hale.

The program of solar investigations outlined in this paper was prepared in substantially its present form in 1894, in connection with other plans for the work of the Yerkes Observatory. The necessity of constructing in our own shop the special instruments required for this work might not have involved any serious delay in the inception of the investigations. But certain demands, which for various reasons could not be set aside, compelled us to construct other instruments before making complete provision for solar research. It will be seen from what follows, however, that considerable solar work has already been done, and that the entire program will shortly be in effect. The principal investigations comprised in the program are as follows :

1. *Direct photography.*—Daily photographs of the Sun on a scale of seven inches (17.7 cm) to the diameter ; large scale photographs of spots and other regions.

2. *Monochromatic photography.*—Daily photographs with the spectroheliograph, for systematic study of the form, area, distribution, and motion of the calcium vapor in faculæ, chromosphere, and prominences. Comparative photographs taken simultaneously in various bright and dark lines, and other special researches.

3. Daily photographs of the spectra : (*a*) of Sun-spots, for the systematic study of the positions and intensities of the widened lines and the bright H and K lines ; (*b*) of various regions of the photosphere, for the study of the bright H and K lines and the detection of possible changes in the position or intensity of dark lines ; (*c*) a special series of photographs taken at the shortest practicable time intervals, near the Sun-spot maximum, in order to register, if possible, such remarkable changes in the reversing layer as are referred to on p. 220.

4. Special researches, radiometric, visual, and photographic,

on the spectrum of the reversing layer and the chromosphere with a large solar image and powerful grating spectroscope.

5. An investigation of the solar rotation, to be determined from displacements of certain narrow bright lines in the spectrum of the chromosphere and prominences, photographed with very high dispersion.

6. Radiometric investigations of various kinds, with particular reference to the level of Sun-spots.

7. Visual observations to supplement those made photographically.

DIRECT PHOTOGRAPHY.

The series of direct photographs of the Sun now in progress is made with the 12-inch (30.5 cm) refractor, which gives an image two inches (5.1 cm) in diameter. These will give place later to a series in which the diameter of the image will be seven inches. In view of the fact that the heliocentric position of all spots is determined at Greenwich, it is not expected to measure these plates. They are intended for use in connection with other photographs, especially those of spot spectra, for the identification of the spots, and the study of their structure. For the latter purpose they are to be supplemented by large scale photographs of special regions.

MONOCHROMATIC PHOTOGRAPHY.

The series of daily photographs of the Sun made with the spectroheliograph of the Kenwood Observatory covers the period, January 1891–June 1896. These photographs were taken with the aid of the 12-inch equatorial refractor referred to above. Had circumstances permitted, the series would have been continued with the same telescope after its removal to the Yerkes Observatory. But unfortunately this could not be done. The telescope was needed for micrometric, photometric, and other work of a general nature, which did not involve the use of large and heavy attachments. It was therefore necessary to remodel the telescope, as it had been especially designed to carry the large Kenwood spectroheliograph. In a series of photographs of this character, it is imperative, for purposes of measurement,

etc., that the entire disk of the Sun should appear on a single plate. Hence the old spectroheliograph, whose slits are only three inches long could not be used to make such a series with the 40-inch (102 cm) Yerkes refractor, which gives a solar image seven inches in diameter. A new and much larger spectroheliograph was accordingly designed for this telescope, while the Kenwood instrument, after the reconstruction required to adapt it to the large refractor, was employed as a solar spectroscope, and later as a spectroheliograph for photographing limited areas.

In designing the large spectroheliograph, the only difficulty arose from the large diameter of the solar image. For full illumination, with a solar image seven inches in diameter, collimator and camera lenses nearly ten inches (25 cm) in diameter would be required. Funds were not available for the purchase of such lenses, and in any event their great weight would have precluded their use. Accordingly Voigtländer portrait lenses, such as were formerly used in photographers' studios, were selected, and after an extensive search among dealers in photographic supplies, two such lenses, of 6½ inches (16.5 cm) clear aperture, were obtained at a small fraction of their original cost. The loss of light at the upper and lower ends of the slit with lenses of this aperture is not sufficient to affect the image at all seriously. At the same time the field is large enough to give an image well defined at the limb. It was decided to mount these lenses in parallel collimator and camera tubes, and to connect them by an optical train consisting of a plane mirror and two 60° prisms, giving a total deviation of 180° to the K line.

The problem of securing the necessary relative motion of instrument and solar image then presented itself. I long ago came to the conclusion that the best form of spectroheliograph is that in which the instrument is moved as a whole, the solar image and photographic plate remaining stationary. In the present case, however, such an arrangement was out of the question, as the motion of an instrument weighing several hundred pounds would set the entire telescope in vibration, and consequently ruin the photographs. Exposures on a trailing star

image, made when the telescope was driven in declination by the slow motion electric motor, indicated that it should be possible to produce with this motor a uniform motion of the solar image across the first slit. It would then only remain to cause a synchronous motion of the plate behind the second slit by a shaft led down the telescope tube from the same motor. This design would not have been chosen for a smaller spectroheliograph, but it seemed to be the best available for the instrument in question.

A photograph of the spectroheliograph, which was completed in 1899, is reproduced in Plate VII, Fig. 2. The above brief description should make its general construction clear. Such details as the method employed to eliminate distortion of the solar image arising from the strong curvature of the spectral lines, the method of setting the K line on the second slit, the adjustments of the mirror and prisms, the occulting disk moving with solar image for prominence photography, the mechanism of the plate-carriage and second slit, etc., need not be discussed here. A statement regarding the results obtained with the instrument will suffice for my present purpose.

Great care had been taken in constructing the spectroheliograph to guard against diffuse and reflected light, and the resulting photographs show that the precautions were effective. In spite of the great curvature of the spectral lines the solar image is circular and free from distortion The network of hot calcium vapor, first shown on the Kenwood photographs in all parts of the solar disk, was found to persist throughout the spot minimum, at a time of feeble solar activity. It occurs at the poles as well as at the equator, and may doubtless be considered a permanent feature of the solar structure. With the new spectroheliograph, by giving a suitable exposure, photographs were obtained showing this reticulation almost alone, with only a faint background, due to the white light of the solar disk. This fact affords the best evidence of the excellent contrast of negatives taken with the instrument,[1] which is not adequately shown in the reproduction of a part of one of the photographs (Fig. 1).

[1] In a recent number of the *Comptes Rendus* (September 29, 1902) M. Deslandres remarks:

"Ces deux spectrographes des formes et des vitesses de Meudon sont actuelle-

PLATE VII.

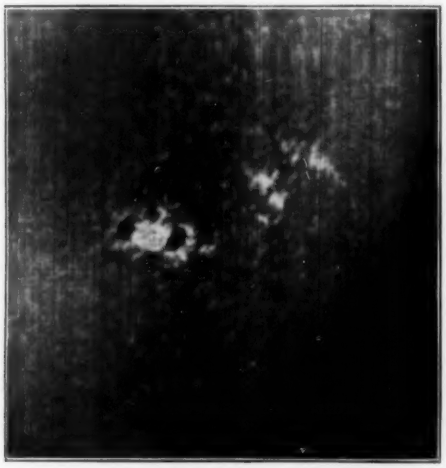


FIG. 1.—Sun-spot of March 6, 1900.
Photographed with the Yerkes Spectroheliograph.

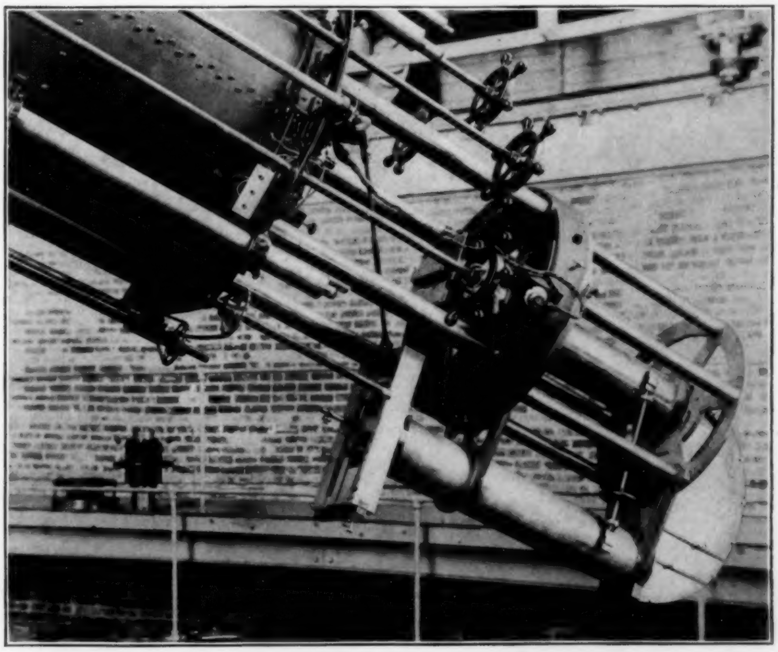


FIG. 2.—Spectroheliograph attached to 40-inch Yerkes Refractor.

A periodic error, probably due to the absence of suitable end-thrust bearings on the screw used to move the plate, was easily removed. There remained another periodic error which produced lines on the plates at regular intervals of about one-third of a millimeter. These were less conspicuous than the lines commonly present on plates taken with spectroheliographs driven by a clepsydra, but they were nevertheless objectionable, especially because of the serrated effect they tended to produce at the solar limb. It was also found, however, that even with perfectly uniform motion of the telescope and plate the limb was serrated whenever the telescope was swaying in the wind or when the seeing was poor. Such effects had been obtained with the Kenwood spectroheliograph, but on account of the smaller size of the telescope and of the solar image they were less noticeable.

After the construction of a horizontal reflecting telescope of 61½ feet (18.7 m) focal length had been decided upon, I concluded to transfer the large spectroheliograph from the 40-inch to the new telescope as soon as completed, and to use the remodeled Kenwood instrument, either as a spectroheliograph or spectrograph, for regular work with the large refractor. The great weight of the large spectroheliograph (about 700 pounds, or 317 kg) made it impossible to attach it to and detach it from the telescope very rapidly, and hence no spectroscopic work could be done with the telescope on days when the spectroheliograph was in use. With the horizontal telescope it can be moved into or out of position in a moment, and hence it will not interfere with the instant use

ment les seuls en service dans le monde entier; car le spectrographe des formes, ou spectrohéliographe, réalisé par Hale à Chicago, n'a pas été remonté lors de son transfert à l'Observatoire Yerkes en 1897. Mais j'ai appris récemment que les Anglais, sur l'initiative de Sir Norman Lockyer, ont commandé deux séries d'appareils similaires, qui seront placées en Angleterre et aux Indes." As M. Deslandres has made a similar statement in a previous article, it is perhaps worth while (without further mention of the Yerkes Observatory) to recall the fact that he has overlooked the systematic work of Mr. Evershed, who first used a spectroheliograph in 1893 (some months before M. Deslandres' first spectroheliograph was constructed), and that of Dr. Kempf, which has been in progress for several years at the Potsdam Observatory, and is reported annually by Director Vogel in the *Vierteljahrschrift der Astronomischen Gesellschaft*. Experimental work with a spectroheliograph has also been in progress for several years at Sir Norman Lockyer's Observatory.

of the large spectroscopes and other attachments provided for this instrument. At present, therefore, spectroheliographic work with the 40-inch telescope is confined to the limited regions which can be photographed with the Kenwood instrument.

THE SPECTRA OF SUN-SPOTS.

The remarkable peculiarities of the spectra of Sun-spots seem to deserve more attention than they have hitherto received from spectroscopists. With the exceptions noted below, all observations of the widened lines have been made visually, and for the most part they have been confined to a limited number of the most widened lines in the spectra. Professor Young's important observations of spot spectra, especially those made at Mount Sherman in 1872, comprise a valuable record of all the widened lines then visible. If systematic observations of this kind could have been carried on daily throughout an entire Sun-spot cycle, it is probable that our knowledge of the nature of Sun-spots would have been considerably increased. On account of the multitude of widened lines present, and the consequent difficulty of recording all of them within the time available for observation, it would be difficult to make such a series. Nevertheless, a series in which these conditions were partially fulfilled was carried on by Mr. Maunder at Greenwich, principally during the years 1877 to 1883, and his results constitute one of the most important sources of information regarding Sun-spot spectra.[1] Another important series is that of Father Cortie, who recorded the widened lines in the region C to D during the years 1880–1889.[2] In the observations systematically conducted under the direction of Sir Norman Lockyer for many years, attention has been confined to the six "most widened lines" between D and *b* and the six most widened lines between *b* and F.[3] The program of solar observations prepared by the Observatories Committee of the Royal Society for the Astrophysical Observatory at Kodaikanal, India, provides for a similar series of observations. It also states "that other widened lines should be noted."

[1] *Greenwich Spectroscopic and Photographic Results.*

[2] *Memoirs R. A. S.*, Vol. L, pp. 30–56. [3] *Proceedings of the Royal Society.*

In view of the importance of the conclusions which may be based on the study of Sun-spot spectra, it has seemed to me that every effort should be made to record systematically, not merely the twelve most widened lines, but all of the lines which are distinctly affected in the spectra. In my work at the Kenwood Observatory from 1891 to 1896, I found that recourse should be had to photography, if possible, on account of the large amount of time required to make a complete record visually. Experiments in the photography of spot spectra were accordingly instituted, and some degree of success was attained. The 2-inch solar image given by the 12-inch refractor was too small, however, to permit any but the strongest of the widened lines to be photographed. Experiments with an enlarged solar image were therefore made, but as the instrumental conditions were not favorable, it was decided to postpone the work until it could be undertaken with the 40-inch refractor of the Yerkes Observatory. The difficulty arising from the use of a small solar image is doubtless what interfered so seriously with the photographic experiments on spot spectra made by Father Sidgreaves at Stonyhurst. It was probably because of the encroachment of photospheric light on the spot spectrum that he was led for a time to doubt the objective existence of widened lines. With the larger solar image given by the 23-inch (58.4 cm) Princeton refractor, Professor Young in 1893 obtained photographs of spot spectra which showed a considerable number of widened lines. An engraving from one of these photographs is given on p. 217 of the (1898) revised edition of Professor Young's *General Astronomy*. This photograph shows, as was well known from visual observations, that while many lines are widened in the spectra of Sun-spots, others are materially reduced in intensity.

The following program of observations of Sun-spots, prepared by Mr. C. Michie Smith for the Kodaikanal Observatory, is given in his report on the Kodaikanal and Madras observatories for the period April 1 to December 31, 1901:

(*a*) A daily examination of the Sun's surface for spots.

(*b*) When a spot of sufficient size is present, one or more photographs of

the spectrum with the necessary comparison spectra will be taken. It is intended to take photographs of as large a part of the spectrum as possible, so that the taking of the photographs will occupy a considerable time; only a small part of the spectrum can be taken at a time.

(*c*) If it be found impracticable to photograph the whole of the visible spectrum, the photographs will be supplemented by eye-observations.

(*d*) The photographs will be at once developed.

(*e*) The measurement and reduction of the negatives will, as far as possible, be kept up to date, but as there will always be plenty of cloudy days on which this work can be done, the first duty on bright days will always be the making of observations.

The program of Sun-spot observations which the Observatories Committee of the Royal Society has substituted for the program proposed by Mr. Smith, gives first place to the visual observations of the twelve most widened lines referred to above. It also provides that "after the above requirements are fulfilled, it is desirable that if possible photographs should be taken of Sun-spot spectra, for which, it is to be noted, comparison spectra, other than the solar spectrum, are unnecessary." It should be added that Mr. Smith's general solar program, as well as that of the Royal Society Committee, provides also for photography with the spectroheliograph.

A program of Sun-spot observations which I prepared in 1894 is as follows:

1. Daily photographs of the Sun, on a scale of seven inches to the Sun's diameter, to identify spots and to give their general form and heliographic position.

2. Enlarged photographs of spots, to record details of structure.

3. Monochromatic photographs with the spectroheliograph to show the distribution of calcium vapor.

4. Photographs of the spectra of spots, supplemented by visual observations.

5. Photographs of the H and K lines, with very high dispersion, at regularly spaced points over the entire solar surface, to show the radial motion of the calcium vapor, particularly in the vicinity of Sun-spots. In certain cases, where special accuracy is required, these photographs are to include comparison spectra.

6. Measurements of the heat radiation of spots, and also of the photosphere near the spot and at the center of the Sun.

In a discussion of the observations the changes in intensity of

PLATE VIII.

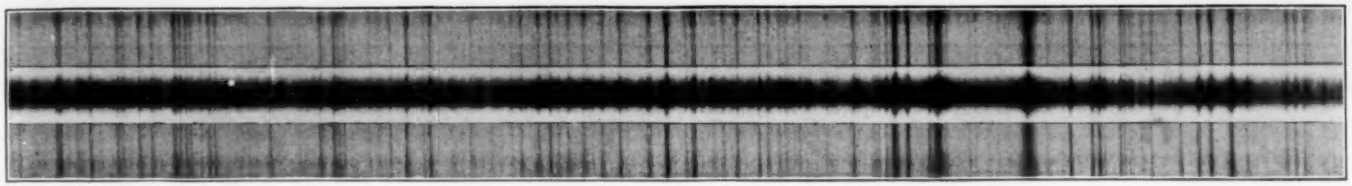


FIG. 1.—"Bands" and Widened Lines in the Spectrum of a Sun-spot.

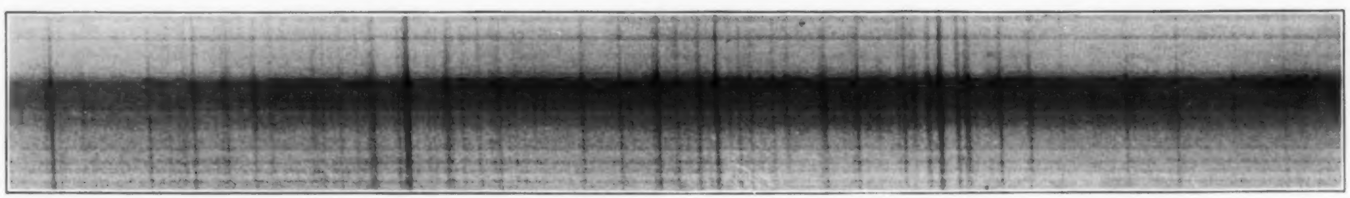


FIG. 2.—Widened Lines in the Spectrum of a Sun-spot.

the spot lines would thus be considered in connection with the heliographic position of the spots, their form and structure, the distribution and motion of calcium vapor in their vicinity, and the amount of their heat radiation.

In the present preliminary paper, I wish to consider briefly only that part of this program which relates to the photographic spectra of spots. Up to the present time all of the photographs have been made by Mr. Ellerman with the remodeled Kenwood solar spectograph attached to the 40-inch telescope. For the most part they have been taken in the second spectrum of a large plane grating having 20,000 lines to the inch (7,874 to the cm). The camera, which is of 3¼ inches (8.3 cm) aperture, has a focal length of 42½ inches (108 cm). With this scale all of the more conspicuous of the widened lines are easily recorded. Photographs showing some of these widened lines are reproduced in Plate VIII[1]. One of these is of special interest, as it gives a photographic record of many of the "bands" seen for the first time by Maunder on November 27, 1880, and frequently observed by him during the three succeeding years. The following table contains the wave-lengths of some of these bands as measured on one of our photographs by Mr. Barrett, together with the positions of the corresponding bands as determined by Maunder in April 1882.[2]

Three facts have become clear from the work so far accomplished: (1) that a considerably greater linear dispersion will be required in order to record photographically the faintest widened lines and other of the less conspicuous features of the spectrum; (2) that a solar image having a diameter of more than seven inches would be very advantageous, especially for the smaller spots; (3) that in order to determine, with high precision, whether the spot lines are displaced from the normal positions of the corresponding solar lines, a comparison spectrum will be essential. The new apparatus which has been constructed for the work will therefore comprise a coelostat

[1] Unfortunately these reproductions fail to bring out clearly the widened lines, which are well shown on the original negatives.

[2] *Greenwich Spectroscopic and Photographic Results*, 1882, p. 10.

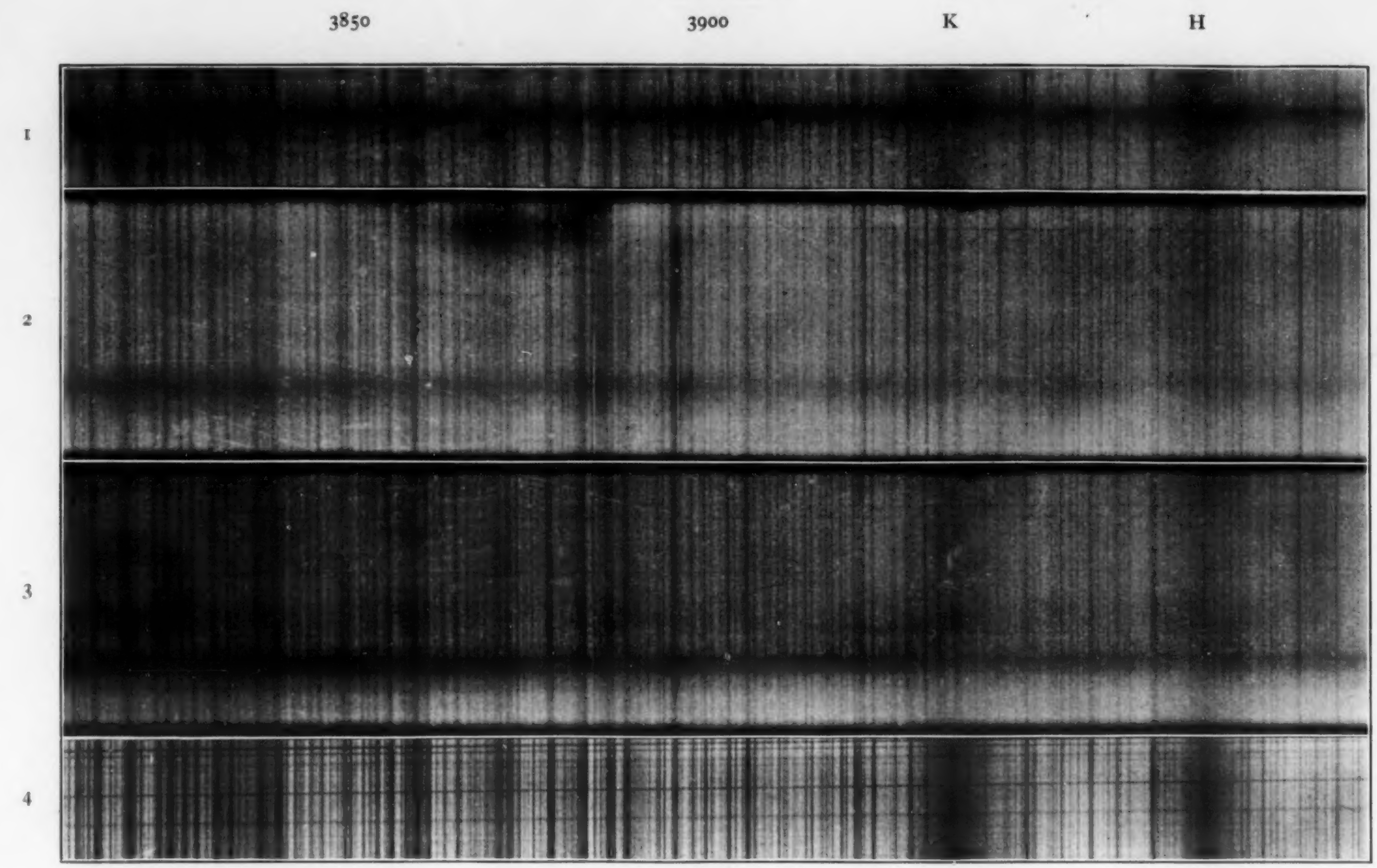
Yerkes Photograph			Maunder	
Wave-length	Width	Character	Wave-length	Width
5096.33	0.54	double	5094.0 } triple 5096.5 }	
5100.65		very indistinct		
5101.66		broad, hazy	5101.0	0.2
5111.86	0.57	double, perhaps triple		
5113.28	0.96	triple ?	5113.8	0.8
5114.58	0.45	double		
5116.60	1.28	triple	5116.0	0.8
5118.88	1.68	triple	5117.8	0.8
5120.45	0.48	narrow	5120.1	0.8
5122.36		narrow		
5134.76	0.86	triple		
5135.29		narrow		
5136.38	0.67	triple? ?	5136.4	0.3
5138.75	0.59	band	5138.3	0.3.
5140.44		narrow		
5141.38	0.51	band		
5144.03	0.67	double		
5147.72	0.64	double ?		
5150.03	1.08	double	5150.2	1.0
5156.80	1.02	triple	5156.2	0.7
5157.86		narrow		
5160.15	0.86	double	5159.6	0.6
5163.06	0.76	double	5162.3	0.8
5163.72	0.37	narrow band		

reflecting telescope of 165 feet (50.3 m) focal length, giving a solar image about 20 inches (50 cm) in diameter, and a large spectroscope, with which a concave grating of 21 feet (6.4 m) radius, or a plane grating with collimator of 18 feet (5.5 m) focal length, and cameras of about equal focal length, can be employed.

A REMARKABLE DISTURBANCE OF THE REVERSING LAYER.

In February 1894, while engaged in making a series of photographs of the solar spectrum with the spectrograph attached to the 12-inch Kenwood refractor, Mr. Ellerman unconsciously recorded a phenomenon which appears to be quite unique. A series of exposures was made on a single plate, in order to find the relative exposure times required in spectra of the first, second, third, and fourth orders of the grating. The 51 mm image of the Sun was so adjusted that the image of a spot fell exactly on the slit. A diaphragm limited the width of each

PLATE IX.



1. Spectrum just before the Disturbance. 2. "Abnormal" Spectrum. 3. "Intermediate" Spectrum. 4. Normal Solar Spectrum.

A Remarkable Disturbance of the Reversing Layer.

strip of spectrum to 6.5 mm, corresponding to about one-eighth of the Sun's diameter or 4⅛′ of arc. Unfortunately, as the photographs were intended merely for the purpose of ascertaining the relative exposure times, and not for spectroscopic study of the Sun, no record of the plate was made in the note-book. As the peculiarities of the spectra were not noticed until some months later, we have no way of determining the date on which the photographs were made or of identifying the spot in which the disturbance centered. A large spot in the southern hemisphere, which may have been the one in question, is first shown near the east limb on a spectroheliograph plate taken on February 16. Subsequent plates in the daily series show the changes in this spot as it passed across the disk, but give no evidence of any unusual disturbance. The available evidence on the spectrum plates, indicates, however, that the phenomenon was very short-lived, and for this reason it might easily have escaped detection. Furthermore, the bright H and K lines, instead of showing a great increase of intensity, as in certain eruptions recorded with the spectroheliograph, in this case disappeared entirely. Hence any record of the disturbance made with this instrument would have involved the *disappearance* of the bright calcium region surrounding and partly covering the spot.

The photographs are reproduced in Plates IX and X. Fig. 1 is the spectrum, showing few, if any, deviations from the normal, which was taken just before the disturbance occurred. All of the spectra were in the third order of a plane grating having 14438 lines to the inch (5684 to the cm), with a camera of 3¼ inches aperture and 42½ inches focal length. The spectra were all overexposed, and consequently show little contrast. Nevertheless the ordinary reversals of the H and K lines can be seen over and near the spot band in Fig. 1. A few moments later, as Fig. 2 shows, the disturbance was at its height. In the seven spectra photographed before the disturbance occurred, and also in the four following ones, the continuous band of absorption due to the spot is clearly shown. In this abnormal spectrum, however, though the band is clearly visible at the two extremities of the spectrum, it is very faint in the region of H and K. It

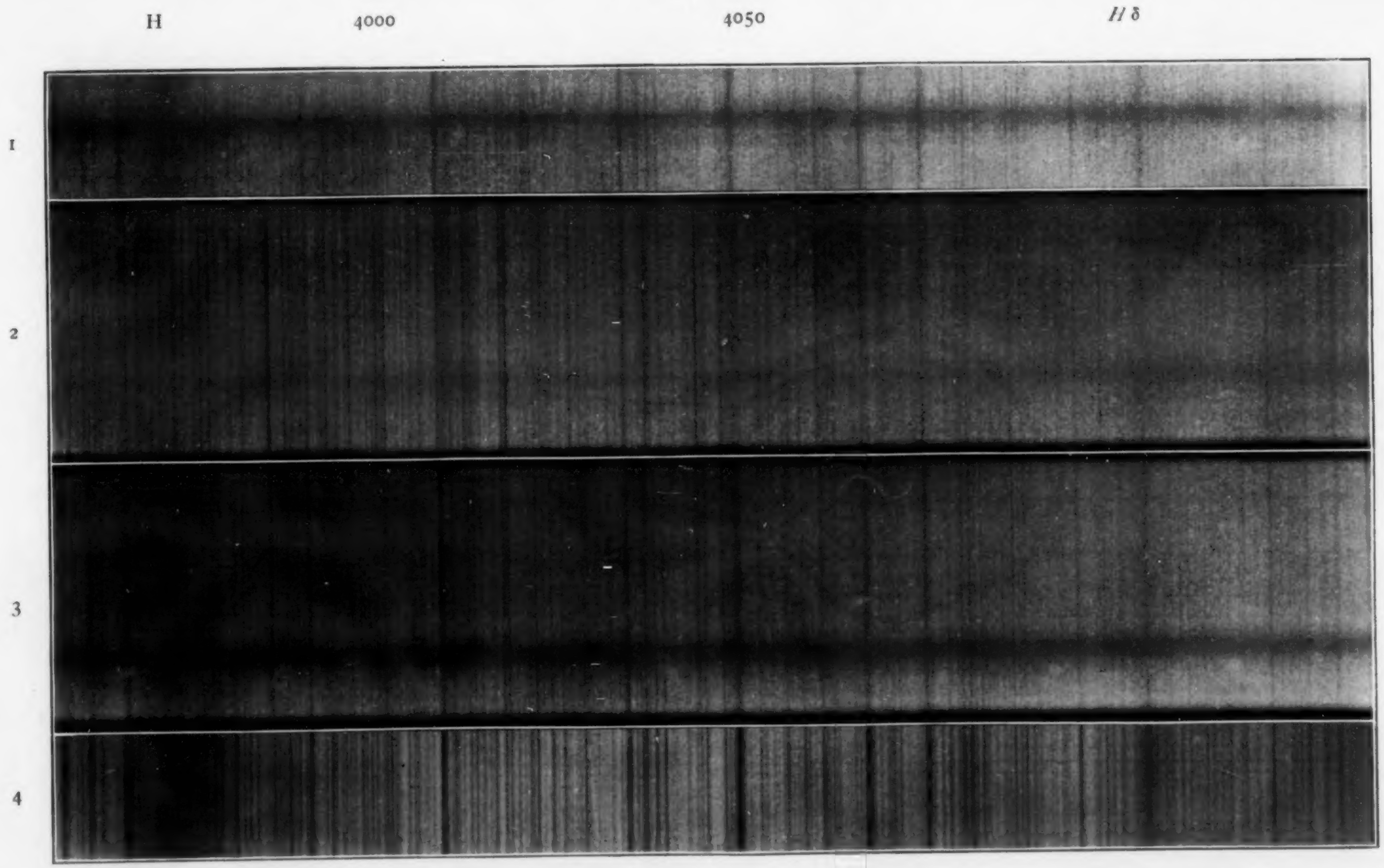
is a curious fact that the greatest changes in selective absorption also occurred in the neighborhood of H and K, and that at the two ends of the negative the lines differ but little from those of the normal solar spectrum. Two narrow bright lines at λ 3884.64 and λ 3896.21 form a striking feature of this spectrum. Indeed, it was through the presence of these lines that the peculiarity of the spectrum was first recognized.

Fig. 3 shows the spectrum as photographed a few moments later. As the slit apparently remained at about the same point on the spot throughout the twelve exposures obtained on the plate, it is extremely probable that the change in the spectrum represents a later stage of a short-lived phenomenon. This spectrum is intermediate in character between the abnormal spectrum of Fig. 2 and the normal solar spectrum. The bright lines, which may be too faint to appear in the illustration, are shorter than before, and their wave-lengths have changed to λ3884.28 and λ3895.98 respectively. Strong dark lines of the normal solar spectrum, which are faint in the abnormal spectrum, have regained some of their intensity, while other lines, peculiar to the disturbance, are much less pronounced than before.

The next photograph was taken in the fourth order spectrum, and shows only the normal spectrum, with the H and K lines once more reversed across the spot. The dark shades at H and K, which are so inconspicuous in the spectra of the disturbance, have also resumed their usual appearance. This spectrum is not given here, but a photograph of the normal spectrum, taken with proper exposure on another date, is reproduced in Fig. 4 for comparison.

Every spectroscopist will understand why I have hesitated to publish these spectra. So far as I know, the phenomenon is quite without precedent, and I could hardly believe it possible that the solar spectrum should undergo so complete a change throughout an area whose length was at least one-eighth of the Sun's diameter. Had the disturbance been confined to the spot it would have seemed far less remarkable, though even then without precedent; but the photographs show it to extend far beyond the spot, with few, if any, indications that the width of

PLATE X.



1. Spectrum just before the Disturbance. 2. "Abnormal" Spectrum. 3. "Intermediate" Spectrum. 4. Normal Solar Spectrum.

A REMARKABLE DISTURBANCE OF THE REVERSING LAYER.

the spectrum was sufficient to include the entire disturbed area. Even after the two peculiar bright lines had led to an examination of the plate, we were inclined to assume that the effect was produced by the chance superposition of two spectra, photographed in different positions of the grating. It soon appeared, however, that the spectra could not be accounted for in this way. Copies were then sent to several spectroscopists for examination, with the request that an explanation referring the phenomenon to some origin other than solar be supplied, if possible. As no such explanation was forthcoming, I measured the lines of one of the spectra, and intended to measure those of the other. I was prevented from doing so, however, by an eye affection, and accordingly requested Mr. Adams to make the necessary measures. His results, which include both spectra, are given in the following table. The intensities of the lines, which are on Rowland's scale, were estimated independently for the two spectra.

An examination of these results will show that most of the lines of the "abnormal" and "intermediate" spectra are solar lines in Rowland's table, but in many cases so changed in intensity as to be quite unrecognizable. From the limit of the spectrum in the ultra-violet to about λ 3865 the abnormal spectrum corresponds fairly well with Rowland's map. Hence, comparatively few lines in the intermediate spectrum were measured above this point. The spectra now begin to show marked differences, but these relate to the intensity rather than to the position of the lines. The group of lines which forms a blend at about λ 3878.5 in the solar spectrum, with a combined intensity of 22, is absent from the abnormal spectrum, though it appear with full intensity in the intermediate spectrum. Similar cases occur at λλ 3883.24, 3889.05, 3903.11, 3921.71, 3948.91, 3953.02, 3961.67, etc. The last-named line is one of a strong pair between H and K in the second subordinate series of aluminium. In the spark between aluminium poles in water, and in other cases in the laboratory, I have found these lines to vary together. In the present instance, however, the other member of the pair (at λ 3944.19) is but little reduced in intensity in the abnormal spectrum, while its

Wave-length			Intensity			Substance
Rowland	ntermediate	Abnormal	Rowland	Inter-mediate	Abnormal	
3747.098	Spectrum poor	3747.10	5	..	6	*Fe*, –
3748.408	few lines measured	3748.38	10	..	10	*Fe*
3758.375	....	3758.32	15	..	15	*Fe*
3760.196	....	3760.21	5	..	5	*Fe*
3761.487	3761.45	3761.47	9	9	8	*Ti, Fe*
3762.435	....	3762.47	4	..	4	–, *C, C*
3763.945	....	3763.97	10	..	10	*Fe*
3765.689	....	3765.71	6	..	8	*Fe*
3779.598	....	3779.52	4	..	5	*Fe*
3783.674	....	3783.67	6	..	6	*Ni*
3788.046	3788.01	....	9	10	..	*Fe*
3793.656	....	3793.68	8	..	2	–, –, *Fe, Ni*
3795.150	....	3795.13	10	..	7	*V, Fe*, –
3799.693	....	3799.66	7	..	8	*Fe*
3801.873	....	3801.96	5	..	3	*Fe, Fe*
3805.486	3805.49	3805.50	6	5	6	*Fe*
3809.724	....	3809.76	4	..	5	*Mn*
3811.989	....	3811.95	4	..	3	*Fe*, –
3813.100	3813.10	3813.03	5	5	5	*Fe*
3814.698	3814.67	3814.73	8	9	8	*Fe-C, C*
....	....	3815.77	..	..	6	......
3817.72	....	3817.72	3	..	4	*Fe-C*
3820.586	....	3820.58	25	..	20	*Fe-C*
3826.027	....	3826.07	20	..	20	*Fe*
3827.980	....	3827.95	8	..	8	*Fe*
3835.509	....	3835.47	1	..	2	*C (H?)*
3838.435	....	3838.43	25	..	25	*Mg-C*
3840.580	....	3840.62	8	..	9	*Fe-C*
3843.195	....	3843.19	2	..	2	*Fe-C*
Blend?	....	3845.44	..	..	7	......
3846.924	....	3846.85	8	..	10	*C, C, Fe, C*
3848.007	....	3848.08	2+	..	5	*C, C, C*
3850.118	3850.11	3850.07	10	10	10	*Fe*
....	....	3850.83	..	..	4	......
....	....	3851.72	..	..	3	......
3852.714	....	3852.72	4	..	4	*Fe*
3853.620	....	3853.59	2	..	2	*C*
3854.707	....	3854.66	2	..	5	*C*
....	....	3855.61	..	..	3	......
3856.58	....	3856.58	10	..	9	*Fe, C?*
3858.924	....	3858.94	4	..	7	*C*,-, *C?*
3860.055	....	3860.11	20	..	20	*Fe -C*
3861.769	....	3861.67	5	..	8	*C, C, C*
3862.660	....	3862.69	3	..	3	*C?*, –
3863.875	....	3863.92	4	..	3	*C, Fe*
3865.674	3865.64	3865.66	7	8	6	*Fe-C*
....	....	3866.24	..	8	..	......
3867.36?	3867.28	....	3	6	..	*Fe-C*
3867.832	....	3867.83	2+	..	3	*C-V, C-*
Blend?	3869.54	....	6	7	..	*Fe--C, C, C C*
3869.725	....	3869.77	5	..	8	*Fe-C, C, C*
....	....	3871.16	..	..	5	......

Wave-length			Intensity			Substance
Rowland	Intermediate	Abnormal	Rowland	Intermediate	Abnormal	
3871.963	....	3871.96	2	..	7	*Fe*
Blend?	3872.85	3872.80	..	15	5	*Fe, C*
....	....	3873.32	..	..	3	......
3874.091	3874.10	....	4	9	..	*Co-C*
3875.025	3875.05	....	5	6	..	*C, C, V*
3875.355	....	3875.30	5	..	6	*V, Ti-C, C*
Blend?	3876.04	....	..	..	..	......
3876.194	....	3876.11	5	..	8	*Fe*
3877.051	....	3877.06	8	..	7	*Co-C, C*
3875.152	....	3878.11	8	..	10	*Fe-C*
Blend	3878.47	....	22	25	..	*Fe, Co*
3878.767	....	3878.75	11	..	12	*Fe, Co-Fe*
3879.716	....	3879.73	1	..	6	*C*
Carb'n iden-	....	3880.24	..	..	9	......
tifications	....	3880.60	..	..	8	......
possible	....	3881.05	..	..	6	... ..
....	....	3882.11	..	..	8	......
....	....	3882.82	..	..	7	......
Blend	3883.34	....	..	12	..	......
3883.462	....	3883.46	3	..	12	*C–, C*
....	3884.28*	....	..	..	..	......
3884.518	3884.51	....	2	6	..	*Fe*
....	....	3884.67*	..	..	..	......
3884.780	3884.85	....	2	3	..	*Ca, Fe*
3885.327	3885.33	....	4	4	..	*Fe, FeCr*
....	....	3885.44	..	..	5	......
3886.434	3886.44	3886.38	15	12	12	*Fe*
3887.196	3887.21	3887.20	7	8	7	*Fe*
....	....	3888.03	..	..	4	......
3888.560	....	3888.50	2	..	4	......
Blend	3889.05	....	..	15	..	*Fe, Mn*
Blend	....	3889.26	..	..	8	*Fe, Mn*
....	....	3889.71	..	..	3	......
3890.538	....	3890.49	2	..	3	*Fe-Zr*
3890.986	....	3891.02	3	..	9	*Fe*
3892.069	3892.04	....	4	5	..	*Fe*
....	....	3892.22	..	..	3	......
3892.698	....	3892.75	2	..	2	*Mn*
3893.542	3893.59	3893.50	4	4	4	*Fe*
3894.181	3894.18	3894.10	10	8	5	*Fe,-Cr, Co*
3895.145	3895.22	....	3	3	..	*Co, Ce*
3895.803	3895.79	....	7	12	..	*Fe*
....	3895.98*	....	..	..	..	......
....	....	3896.21*	..	..	..	......
3897.596	....	3897.58	2	..	2	*Fe*
3898.131	3898.10	3898.10	10	10	12	*Fe, V, Fe*
....	3898.65	....	..	..	..	......
3899.213	3899.30	....	5	4	..	*Fe, –*
3899.850	3899.87	3899.90	8	8	8	*Fe*
3900.681	3900.68	3900.68	5	5	6	*Ti-Fe-Zr*
3901.735	......	3901.77	2	..	2	......
3902.030	3902.08	....	4	4	..	*–, Fe*
3902.399	....	3902.39	3	...	8	*V*

*Bright line.

Wave-length			Intensity			Substance
Rowland	Intermediate	Abnormal	Rowland	Intermediate	Abnormal	
3903.090	3903.11	....	10	12	..	*Fe-Cr*
3903.153	....	3903.21	13	..	12	*Fe – Cr, –, –*
3904.023	3903.98	3904.06	8	5	7	*–, Fe*
3905.660	3905.64	....	12	20	..	*Si*
Blend	....	3905.81	21	..	20	*Si, –*
3906.703	....	3906.75	14	..	4	*Fe, Fe*
Blend?	3907.08	....	5	6	..	*Fe, –*
3908.077	3908.08	....	5	8	..	*Fe*
3908.410	....	3908.41	1	.	15	–
3908.900	....	3908.90	4	..	8	*Cr*
3909.919	3909.93	3909.88	12	12	7	*Fe, Fe, Co-Ca*
3910.469	3910.49	....	2	4	..	–
3910.670	....	3910.67	2	..	6	–
3910.984	3910.98	....	4	5	..	*Fe-V*
Blend?	....	3911.20	..	..	3	*Fe-V, –*
3912.127	3912.14	....	2	3	..	*Cr?*
Blend?	....	3912.36	4	..	7	*Cr?, V?*
3913.123	3913.11	....	2	2	..	*Ni*
3913.395	....	3913.37	1	..	9	–
3913.683	3913.63	....	9	7	..	*Ti-Fe, Fe*
3914.493	3914.50	3914.48	7	8	5	*Fe?, Ti,–, Ni?*
3914.880	....	3914.92	0	..	2	*Fe*
3915.847	....	3915.87	9	..	7	*Fe, Cr, –, Cr –*
3916.545	3916.53	....	3	..	4	–
3916.879	....	3916.84	5	..	10	*Fe*
3917.307	3917.34	3917.25	7	10	3	*Co, Fe*
3917.731	....	3917.67	0	..	5	*Cr*
....	....	3918.11	..	..	3	......
3918.514	3918.53	3918.50	8	7	8	*Fe, Fe*
3919.258	3919.27	3919.24	6	6	3	*Fe, Cr*
3920.410	3920.38	3920.42	10	10	10	*Fe*
3920.984	3921.00	....	2	2	..	......
3921.188	....	3921.21	3	..	3	*Cr-Nd*
Blend?	3921.71	....	9	14	..	*Ti,La–,Zr-Mn*
3921.855	... ...	3921.87	4	..	20	*Zr-Mn*
3923.054	3923.06	3923.03	12	12	12	*Fe*
....	....	3924.10	..	..	6	......
3924.673	3924.67	....	4	4	..	*Ti*
....	....	3924.89	..	..	4	......
3925.347	....	3925.34	4	.	3	......
3925.771	3925.70	3925.76	6	5	8	*–, Fe*
3926.123	3926.15	3926.14	7	5	6	*Fe, –*
3927.585	3927.63	....	1	4	..	–
....	....	3927.77	..	..	25	......
3928.783	....	3928.77	3	..	3	*Cr*
3929.260	....	3929.20	2	..	2	*Fe-Co*
3930.450	3930.46	3930.45	8	15	28	*Fe*
....	....	3931.49	..	..	4	......
....	3932.02	3932.09	..	2	3	......
....	3932.29	....	..	2	..	......
....	....	3932.46	..	..	5	......
....	....	3932.97	..	..	4	......
....	3934.29	....	..	4	..	......

Wave-length			Intensity			Substance
Rowland	Intermediate	Abnormal	Rowland	Inter-mediate	Abnormal	
....	....	3934.43	..	..	3	......
....	....	3935.27	..	..	2	......
....	3937.23	....	..	4	..	......
....	....	3937.39	..	..	10	......
3938.552	3938.58	3938.54	4	5	4	–
....	....	3938.89	..	..	5	......
3939.288 ?	....	3939.31	0	..	3	–
....	3940.25	3940.32		7	12	......
3941.025	3941.02	....	5	3	..	*Fe, Co*
3941.637	....	3841.56	3	..	3	*Cr*
Blend ?	....	3941.99	3	..	2	*Co*,–
3942.558	3942.61	....	5	4	..	–, *Fe*
3943.370	....	3943.42	7	..	2	–, –, *Fe*
3943.721	......	3943.77	1	..	2	–
3944.160	3944.19	3944.16	15	15	12	*Al*
3944.884	....	3944.90	2	..	3	*Fe?*
3945.365	....	3945.31	7	..	6	*Fe*, –, *Co*
3945.993	3945.98	4946.00	1	4	9	*Mn?*
3947.142	3947.17	3947.09	3	4	4	*Fe*
3947.624	3947.58	3947.70*	6	5	8	–, *Fe*
3948.246	3948.30	....	5	..	4	*Fe*
Blend	3948.91	....	13	15	..	*Ti, Fe, Ca, etc.*
Blend	....	3949.15	..	..	9	......
3949.372	3949.33	....	1	2	..	–
3950.102	....	3950.07	5	..	2	*Fe*
Blend ?	3950.33	....	..	10	..	......
3950.497	......	3950.51	2	..	13	*Y*
3951.296	3951.29	3951.30	6	10	15	*Cr, Fe*
3952.754	....	3952.74	4	..	4	*Fe*
Blend	3953.02	....	17	15	..	*Fe, Mn, Co, Cr*
Blend	....	3953.24	10	..	7	*Mn, Co, Cr*
3954.002	....	3953.96	3	..	3	*Fe*
....	3954.15	....	..	6	..	......
....	....	3954.40	..	..	13	......
3954.857	3954.84	....	1	2	..	*Fe?*
3955.461	3955.45	....	6	6	..	–, *Fe*
....	....	3955.58	..	..	5	......
3956.099	3956.10	....	3	3	..	*Fe*
Blend ?	3956.50	3956.42	8	6	8	*Co–Ti, Fe*
3957.177	....	3957.18	7	..	6	*Fe–Ca*
....	....	3957.94	..	..	7	......
3958.355	3958.41	....	5	8	..	*Ti, Zr*
3958.877	3958.86	....	..	2	..	*Fe*
3959.435	....	3959.45	0	..	2	–
3959.972	3959.99	....	1	<2	..	–
....	....	3960.24	..	..	4	......
....	....	3960.96	..	..	2	......
....	....	3961.56	..	..	6	......
3961.674	3961.62	....	20	20	..	*Al*
3962.287	....	3962.26	3	..	11	*Fe?*, –
3963.831	3963.90	3963.83	3	3	5	*Cr*
3964.663	3964.67	3964.75	3	2	2	*Fe*
3965.366	3965.40	....	0	1	..	–*Co*

* Probably Fe λ3947.675 alone.

Wave-length.			Intensity.			Substance
Rowland	Intermediate	Abnormal	Rowland	Inter-mediate	Abnormal	
3965.655]	....	3965.67	2	..	6	*Fe,–*
3966.212	....	3966.17	3	..	3	*Fe*
Blend	3966.80	....	6	6	..	*Ni, Fe*
3966.966	....	3967.02	1	..	6	......
3968.625?	3968.62	3968.68	(700)	7	7	*Ca*
....	....	3969.00	..	..	8	......
3969.413	3969. 4	....	10	4	..	*Fe*
Blend	3970.05	....	7	8	..	*Cr, H*
3970.177	....	3970.26	5	..	10	*H*
3971.475	....	3971.47	5	..	5	*Fe*
....	....	3971.88	..	..	2	......
3972.313	3972.30	....	2	12	..	*Ni*
3972.639	....	3972.61	2	..	12	......
3973.285	....	3973.30	2	..	2	*Co, Co*
3973.772	....	3973.74	6	..	15	*Ni, Zr, Fe, Ca*
3974.774	....	3974.80	2	..	3	*Ni*
3975.350	....	3975.37	2	..	5	*Fe*
3975.985	....	3975.91	2	..	2	*Fe–Mn*
Blend	3976.72	3976.71	5	4	5	*Fe, Fe*
3977.891	3977.90	....	6	8	..	*Fe*
....	....	3978.30	..	..	7	......
3978.809	3978.72	3978.80	3	4	3	*Co, Cr*
3979.664	3979.67	3979.66	4	3	4	*Co*
....	....	3980.39	..	..	2	......
3981.249	....	3981.17	4	..	4	......
3981.917	3981.89	3981.98	4	13	30	*Ti*
3984.091	3984.07	3984.09	7	6	8	*Cr, Fe*
3984.806	3984.81	....	2	2	..	*Ce–Zr*
....	....	3984.97	..	..	4	......
....	......	3985.38	..	..	4	......
3985.526	3985.50	....	6	5	..	*Mn, Fe*
3986.321	3986.34	3986.32	3	4	3	*Fe*
3986.903	3986.90	....	6	8	..	—
3987.241	3987.26	3987.25	5	8	8	– , *Mn, Co*
3988.114	....	3988.05	0	..	2	–
3988.660	....	3988.69	1+	..	2	......
3989.175	3989.18	3989.15	5	4	3	–, –
3989.912	3990.00	3989.91	4	4	11	*Ti*
3991.333	3991.29	....	3	3	..	*Cr, Zr*
3992.971	3992.93	3993.05	3	4	10	*V–Cr*
3993.246	3993.29	....	2	2	..	*Fe*
3994.219	3994.22	....	6	4	..	*Cr, Ni, Fe*
3995.431	3995.43	3995.46	7	5	6	–, *Co*
3996.140	....	3996.17	3	..	3	*Fe*
....	3996.57	....	..	4	..	......
....	....	3996.80	..	..	9	......
3997.577	3997.61	3997.56	6	9	4	......
3998.129	3998.12	3998.08	8	6	8	*Co, Fe*
3998.790	3998.78	3998.75	4	4	4	*Ti*
3999.144	....	3999.17	1+	..	2	*Zr, Fe, Ce*
4000.507	....	4000.49	4	..	10	*Fe, Fe*
4001.315	4001.32	....	3	5	..	–
4002.227	....	4002.20	..	..	2	......

Wave-length			Intensity			Substance
Rowland	Intermediate	Abnormal	Rowland	Inter-mediate	Abnormal	
4002.652?	....	4002.71	0	..	8	*Fe–Ti*
4003.076	4003.09	....	2	2	..	–
4003.912	4003.94	4003.92	3	4	3	*Ce-Ti-Fe*
4005.408	....	4005.41	7	..	10	*Fe*
4005.856	4005.86	4005.87	3	25	5	–
4006.411	4006.35	4006.45	3	2	5	*Ni Fe*
Blend	4006.91	....	6	7	..	*Fe*, –
4007.429	4007.49	4007.44	3	3	3	*Fe*
4008.075	....	4008.09	0	..	4	*Co* – ?
4008.748	....	4008.75	0	..	7	–
4009.056	4009.09	....	5	4	..	–, *Ti*
4009.864	....	4009.85	3	..	3	*Fe*
4010.004	4010.98	4011.03	..	5	3	......
4012.513	4012.58	4012.46	5	4	5	*Nd, Zr, Ti*
....	....	4013.09	..	..	2	......
4013.902	4013.89	4013.95	8	12	15	*Ti-Fe, Fe*
4014.677	4014.66	4014.70	5	9	20	*Fe*
....	....	4015.12	..	..	2	......
4015.760	4015.78	....	3	3	..	–
Blend?	....	4016.46	2+	..	2	–, *Fe*
4017.308	4017.33	4017.33	4	3	4	*Fe*
4017.655	4017.69	4017.70	3	2	2	*Ni? Ni?*
4018.420*	4018.36	4018.42	3	12	8	*Fe*
4019.201	....	4019.22	1	..	7	*Ni-Ce*
....	4019.35	....	..	4	..	......
Blend	4020.46	4020.54	6	10	4	*Mn*, –, *Sc, Fe*
4021.057	4021.09	4021.03	3	2	4	*Co*
4022.018	4021.95	4022.02	5	6	8	*Fe*
....	....	4023.38	..	..	10	......
4023.533	4023.56	....	3	3	..	*Co* –
4024.216	4024.22	4024.23	3	2	2	*Zr, Fe*
4024.815	4024.80	4024.79	7	7	8	*Ti, Fe*
4025.286	4025.29	....	3	3	..	*Ti*
4025.579	....	4025.58	1	..	2	*Cr*
4025.972	....	4025.96	2	..	3	*Co-La*
4027.189	4027.21	4027.18	1	2	3	*Co*
4027.822	....	4027.87	1	..	2	–
4028.497	4028.49	4028.50	4	6	4	*Ti*
....	....	4029.27	..	..	3	......
4029.796	4029.81	4029.77	5	5	5	*Fe-Zr*
4030.918	4030.93	4030.89	9	12	10	*Mn*
4031.904	4031.87	4031.93	4	4	5	*Fe-La, Mn*
4032.117	4032.09	....	2	2	..	*Fe*
4032.729	4032.70	4032.80	6	5	4	*Fe, Fe*
4033.224	4033.24	4033.22	7	12	3	*Fe-Mn*
4033.773	4033.72	4033.81	2	3	15	*Mn, Mn*
4034.456	....	4034.46	2	..	7	–, –
4034.644	4034.63	....	6	10	..	*Mn-Fe*
....	....	4035.32	..	..	2	......
4035.806	4035.81	4035.82	6	12	6	*Co, Mn*
4036.522	....	4036.52	0	..	2	–
....	....	4037.15	..	..	2	......
....	....	4037.72	..	..	3	......

*Perhaps a blend in intermediate spectrum.

Wave-length			Intensity			Substance
Rowland	Intermediate	Abnormal	Rowland	Intermediate	Abnormal	
4039.244	4039.29	....	1	2	..	*Cr*
4039.727	....	4039.74	0	..	2	–
4040.792	4040.78	4040.80	3	6	20	*Fe*
4041.432*	4041.50	4041.43	3	6	3	*Fe*
4042.743	....	4042.75	0	..	2	*Cr, Nd*
Blend?	4044.09	4044.19	5	20	15	*Fe*, –
4044.736	4044.72	4044.71	4	6	4	–, *Fe*
4045.975	4046.01	4045.94	30	30	5	*Fe*
....	....	4046.77	..	..	3	......
....	....	4047.73	..	..	5	......
4048.224	4048.22	4048.26	1	2	4	–
4048.883	4048.91	4048.81	6	6	7	*Zr, Mn-Cr*
....	....	4049.33	..	..	5	......
4049.799	4049.85	....	2	2	..	–, –
4050.830	4050.81	4050.84	2	4	7	*Fe*
4052.070	4052.05	....	3	2	..	*Fe*
Blend	4052.72	....	7	4	..	*Mn, Fe*, –
4053.424	....	4053.43	2	..	5	*Fe*
4053.981	....	4053.94	3	..	3	*Fe-Ti*,
4054.999	4054.96	4055.04	5	8	14	*Fe, Fe-Ti*
4055.701	4055.71	4055.73	6	7	6	*Mn*
4057.466	....	4057.39	4	..	15	*Co, Fe*
4057.668	4057.66	....	7	10	..	–
4058.372	4058.34	4058.34	4	3	4	*Co-Fe*
4058.998	4058.99	4058.92	6	4	10	*Fe, Cr, Mn*
4059.535	4059.53	....	1	6	..	*Mn*
....	....	4059.70	..	..	12	......
....	....	4060.69	..	..	5	......
4061.244	....	4061.26	3	..	5	*Nd*
4061.881	....	4061.86	2	..	2	*Mn*
....	4062.10	....	..	4	..	......
4062.599	4062.60	4062.62	5	4	5	*Fe*
4063.436	....	4063.38	4	..	12	*Fe*
4063.759	4063.74	....	20	20	..	*Fe*
Blend?	....	4064.41	5	..	8	–, *Ti, Ni, Fe*
Blend?	....	4066.47	4	..	8	–, –, *Co*
4067.139	4067.07	4067.09	5	3	5	*Fe*
4067.429	4067.39	....	3	3	..	*Fe*
4068.137	4068.15	4068.11	6	7	3	*Fe-Mn*
4069.221	4069.21	4069.19	2	2	3	......
4070.431	4070.43	4070.44	3	3	6	*Mn*
4070.930	4070.92	....	4	4	..	*Fe*
4071.908	4071.87	4071.91	15	15	15	*Fe*
4072.655	4072.66	4072.64	2	3	3	*Fe*
4073.921	4073.90	4073.87	4	4	4	*Fe*
4074.902	4074.91	4074.90	5	6	5	–, *Fe*
....	4076.24	....	..	4	..	......
4076.823	4076.84	4076.78	9	7	7	*Fe-Zr, Fe*, –
4077.885	4077.88	4077.82	8	10	7	*Sr*
4078.565	4078.56	4078.58	7	6	8	*Fe, Ti*
4079.570	4079.50	....	3	7	..	*Mn*
4079.996	4079.97	4079.98	3	2	5	*Fe*
4080.368	4080.34	....	3	4	..	*Fe, Nd*

*Probably in a blend intermediate spectrum.

Wave-length			Intensity			Substance
Rowland	Intermediate	Abnormal	Rowland	Inter-mediate	Abnormal	
....	....	....	..	..	..	......
....	....	....	..	..	..	......
....	....	4081.77	..	..	2	......
4082.264	4082.24	....	2	4	..	*Fe*
4082.589	....	4082.61	3	..	6	*Sc–Fe–Ti*
4083.095	4083.08	....	4	5	..	*Mn*
4083.783	4083.84	4083.77	7	11	8	*Fe,Mn,Y,Fe*
4084.148	....	4084.17	0	..	2	–
4084.647	4084.60	4084.67	5	6	5	*Fe*
....	....	4085.27	..	..	7	......
4085.455	4085.46	....	5	5	..	–, *Fe*
4086.469	....	4086.40	3	..	3	*Co* –
4087.252	4087.27	4087.23	3	3	3	*Fe*
4088.713	....	4088.72	3	..	6	*Fe*
4089.374	4089.31	4089.36	3	4	3	*Fe*
4090.228	....	4090.19	2	..	3	*Fe*
4091.109	4091.08	....	3	2	..	–
4091.711	4091.77	....	3	4	..	*Fe*
4092.626	4092.64	4092.68	9	9	8	*Fe,Co,Mn,V,Ca*
4095.094	4095.10	4095.09	4	4	4	*Ca*
4096.213	4096.26	4096.19	6	6	7	*Fe,Fe*, –
4097.241	4097.23	4097.23	3	4	3	*Fe*
4098.335	....	4098.28	5	..	4	*Fe*
4098.708	4098.70	....	6	2	..	*Ca?*, –
4099.207	....	4099.23	0	..	4	–
Blend ?	4100.00	....	2+	2	..	*V*, –
4102.000?	4101.95	....	40	7	..	*H,In*
4103.097	4103.10	4103.09	5	6	5	*Si,Mn*
4104.288	4104.29	....	5	4	..	*Fe*
Blend ?	4105.23	4105.23	3	4	3	–, *V*
4106.502	4106.49	....	4	4	..	*Fe,Fe*
4107.649	4107.65	4107.65	5	5	4	*Ce–Fe–Zn*
4108.687	4108.73	....	2	2	..	–
4109.215	....	4109.17	3	..	7	*Fe*
4109.934	4109.96	4110.00	5	6	8	*V,Fe*
4111.940	4111.93	4111.92	4	4	4	*V*
4113.104	4113.09	4113.16	4	4	4	–, *Fe*
4114.606	4114.64	....	4	4	..	*Fe*
4115.330	4115.34	4115.28	3	2	7	*V*
....	....	4116.02	..	..	2	......
4116.746	4116.79	....	2+	4	..	*V,V,Nd?*
4118.008	4118.01	....	2	2	..	–
4118.708	4118.66	....	5	6	..	*Fe*
4119.973	4119.01	4118.96	..	8	10	*Co,Fe*
4120.368	4120.37	....	4	4	..	*Fe*
4121.477	4121.52	4121.44	6	5	2	*Cr–Co*
4121.963	4121.95	....	3	2	..	*Fe,Cr*
4122.673	....	4122.67	3	..	2	*Fe*
4122.710	4122.78	....	4	4	..	*Fe*, –
4123.907	4123.95	4123.92	5	2	4	*Fe*
4126.344	4126.34	4126.34	4	3	4	*Fe*
4127.862	4127.86	4127.86	8	7	..	*Fe,Fe*
4128.251	4128.27	....	6	3	..	*V*

Wave-length			Intensity			Substance
Rowland	Intermediate	Abnormal	Rowland	Inter-mediate	Abnormal	
4130.196	4130.21	....	2	3	..	*Fe*
4132.212	4132.20	4132.24	12	10	10	*V,Fe*
4133.062	4133.08	4133.05	4	5	3	*Fe*
4134.010	4134.02	4134.06	3	4	3	*Fe*
Blend	4134.72	....	12	9	10	*Fe?,V-Fe?,* –
4137.156	4137.20	....	6	3	..	*Fe*
4140.089	4140.10	....	6	4	..	*Fe*
4142.686	4142.70	....	4	4	..	*Cr,* –
4143.603	4143.63	....	6	4	..	*Fe,* –
4144.038	4144.08	....	15	12	..	*Fe*
4146.225	4146.26	....	3	4	..	*Fe*
4147.836	4147.83	....	4	6	..	*Fe*
4149.533	4149.51	....	4	4	..	*Fe*

companion has disappeared. On the other hand, such lines as λλ 3898.13, 3920.41, 3923.05, etc., remain of about uniform intensity, while λλ 3930.45, 3940.25, 3951.30, 3981.92, 3992.97 and others are strongest in the abnormal spectrum. Again, there are many cases where lines are stronger in the intermediate spectrum than in the normal or abnormal spectra. At the less refrangible end of the plate, the lines of both the intermediate and abnormal spectra resemble much more closely the lines of the normal solar spectrum. In both the intermediate and abnormal spectra, several lines are strengthened where they cross the spot band.

In examining the photographs, the greatly reduced intensity of the broad dark bands at H and K will be noticed. Under a microscope the original negative shows the K band to be broken up into a number of fine lines, those on the less refrangible side being the more conspicuous. At H there are some strong metallic lines on the violet side, but on the red side there seem to be two or three fine lines resembling those at K. This is of special interest in view of the fact that Jewell found the shading of the H and K lines broken up into lines on one of Rowland's photographs of the solar spectrum; he particularly remarks that the general shading of H and K on this plate is unusually weak.[1] On another occasion, with an arc produced by an extremely powerful

[1] Astrophysical Journal, **8**, 51, 1898.

current, Jewell also succeeded in resolving the shadings of the calcium lines. In the present spectra, however, there is no such uniformity in the spacing of the lines as Rowland's photograph shows.

I had intended to photograph this region in the spectra of certain stars for comparison with the above results, and to make some laboratory investigations with the same end in view. As the Sun-spot maximum is approaching, however, I have thought it best to publish the results as they stand. In view of the importance of recording other similar phenomena, it is to be hoped that a plan can be arranged, perhaps through co-operation, by means of which photographs of the solar spectrum, in the neighborhood of Sun-spots, can be taken daily at very short time intervals.

YERKES OBSERVATORY,
November 6, 1902.

DETERMINATION OF THE INTENSITY-RATIOS OF THE PRINCIPAL LINES IN THE SPECTRA OF SEVERAL GASEOUS NEBULÆ.

By J. SCHEINER and J. WILSING.

AT the request of the editors of the ASTROPHYSICAL JOURNAL, we communicate here a short abstract of our detailed paper on the intensity-ratios of the principal lines of the nebular spectrums recently published in *Astronomische Nachrichten.*[1]

The measures were made with a spectro-photometer, constructed on Crova's principle, attached to the great refractor. By a special arrangement of the eyepiece of the spectro-photometer we were able to compare the nebular lines with objects almost exactly like them in appearance. The intensity of the photometer lamp was determined on every observing night by comparison with a constant source of light (benzine lamp), so that the observations could also be utilized for deriving the relative brightness of the first nebular line in the different nebulæ.

Rigorous photometric comparisons are only possible between radiations of precisely the same wave-lengths, a condition which is fulfilled by the arrangement of our observations. But this carries with it the fact that we do not obtain the desired intensity-ratios of the three lines, $\frac{J_1}{J_2}$ and $\frac{J_1}{J_3}$, directly, but in terms of the corresponding ratios in the spectrum of the photometer lamp. The latter are, however, of a purely accidental character, dependent upon the temperature of the carbon filament of the incandescent lamp used as source, and upon the dispersion of the spectrograph. They are designated below as $\frac{1}{\alpha_2}$ and $\frac{1}{\alpha_3}$.

The following table contains a summary for the two observers of the values of

$$\log \alpha_2 \frac{J_1}{J_2}, \quad \log \alpha_3 \frac{J_1}{J_3}$$

[1] *A. N.*, 159, 181, 1902.

and their corresponding natural numbers, together with the mean values for the different nebulæ:

1901	Wilsing		Scheiner		Wilsing		Scheiner	
	$\log \alpha_2 \frac{J_1}{J_2}$	$\alpha_2 \frac{J_1}{J_2}$	$\log \alpha_2 \frac{J_1}{J_2}$	$\alpha_2 \frac{J_1}{J_2}$	$\log \alpha_3 \frac{J_1}{J_3}$	$\alpha_3 \frac{J_1}{J_3}$	$\log \alpha_3 \frac{J_1}{J_3}$	$\alpha_3 \frac{J_1}{J_3}$
				G.C. 4234				
May 20	0.428	2.7	0.387	2.4	0.637	4.3	0.607	4.0
20	0.439	2.7	0.362	2.3	0.787	6.1	0.661	4.6
21	0.515	3.3	0.407	2.6	0.943	8.8	0.748	5.6
21	0.383	2.4	0.450	2.8	0.717	5.2	0.672	4.7
22	0.447	2.8	0.330	2.1	0.849	7.1	0.627	4.2
22	[0.601]	[4.0]	0.411	2.6	0.752	5.6	0.763	5.8
28	0.451	2.8	0.329	2.1	0.794	6.2	0.901	8.0
June 5	0.503	3.2	0.371	2.3	0.836	6.9	0.802	6.3
7	0.549	3.5	0.354	2.3	0.957	9.1	0.766	5.8
	0.464	2.91	0.377	2.38	0.808	6.43	0.727	5.33
				G.C. 4373				
May 21	0.411	2.6	0.467	2.9	0.517	3.3	0.528	3.4
21	0.465	2.9	0.401	2.5	0.509	3.2	0.454	2.8
22	0.450	2.8	0.422	2.6	0.591	3.9	0.702	5.0
28	0.515	3.3	0.365	2.3	0.642	4.4	0.550	3.5
June 5	0.568	3.7	.....	...	0.620	4.2	.....	...
	0.482	3.03	0.414	2.59	0.576	3.77	0.559	3.62
				G.C. 4390				
June 5	0.432	2.7	0.365	2.3	0.681	4.8	0.712	5.1
7	0.483	3.0	0.487	3.1	[1.124]	...	0.823	6.7
July 10	0.293	2.0	0.218	1.7	0.698	5.0	0.642	4.4
11	0.482	3.0	0.390	2.5	0.683	4.8	0.734	5.4
Aug. 10	.....	...	0.261	1.8	.....	...	0.628	4.2
	0.423	2.65	0.344	2.21	0.687	4.86	0.708	5.10
				N.G.C. 6790				
July 11	0.372	2.4	0.386	2.4	0.884	7.7	1.108	12.8
12	0.537	3.4	0.327	2.1	0.994	9.9	0.932	8.6
Aug. 9	.....	...	0.416	2.6	.....	...	1.133	13.6
10	.....	...	0.273	1.9	.....	...	0.901	8.0
Nov. 9	0.417	2.6	.....	...	.....	...	.....	....
	0.442	2.77	0.351	2.24	0.939	8.69	1.019	10.40

1901	Wilsing		Scheiner		Wilsing		Scheiner	
	$\log a_2 \frac{J_1}{J_2}$	$a_2 \frac{J_1}{J_2}$	$\log a_2 \frac{J_1}{J_2}$	$a_2 \frac{J_1}{J_2}$	$\log a_3 \frac{J_1}{J_3}$	$a_3 \frac{J_1}{J_3}$	$\log a_3 \frac{J_1}{J_3}$	$a_3 \frac{J_1}{J_3}$
				G.C. 4514				
May 22	0.355	2.3	0.401	2.5	0.599	4.0	0.607	4.0
28	0.356	2.3	0.403	2.5	0.603	4.0	0.617	4.1
June 5	0.400	2.5	0.342	2.2	0.664	4.6	0.667	4.6
7	0.448	2.8	0.402	2.5	0.613	4.1	0.712	5.2
July 11	0.417	2.6	.....	...	.....	...	.....	...
12	0.502	3.2	0.399	2.5	0.657	4.5	0.610	4.1
16	0.470	3.0	0.533	3.4	0.765	5.8	0.722	5.3
	0.421	2.64	0.413	2.59	0.650	4.47	0.657	4.54
				N.G.C. 6891				
July 12	0.501	3.2	0.479	3.0	0.736	5.45	0.823	6.7
16	0.453	2.8	0.502	3.2	.....	....	.....	...
Aug. 9	.....	...	0.362	2.3	.....	....	0.605	4.0
10	.....	...	0.424	2.7	.....	....	.....	...
Nov. 9	0.440	2.8	0.266	1.8	.....	....	0.919	8.3
	0.465	2.92	0.407	2.55	0.736	5.45	0.782	6.05
				N.G.C. 7027				
July 16	0.457	2.9	0.446	2.8	1.023	10.5	0.993	9.8
Aug. 9	.....	...	[0.668]	[4.6]	.....	....	0.934	8.6
10	.....	...	0.399	2.5	.....	....	0.859	7.2
Oct. 16	0.481	3.0	0.374	2.4	1.104	12.7	0.918	8.3
16	0.594	3.9	0.400	2.5	0.947	8.9	0.932	8.6
Dec. 12	.....	...	0.381	2.4	.....	....	1.018	10.4
28	0.388	2.4	.....	...	0.857	7.2	.....	...
	0.480	3.02	0.400	2.51	0.983	9.62	0.942	8.75
				G.C. 4964				
Aug. 9	.....	...	0.515	3.3	.....	...	0.743	5.5
10	.....	...	0.334	2.2	.....	...	0.630	4.3
Nov. 9	0.504	3.2	0.357	2.3	0.898	7.9	0.797	6.3
9	0.493	3.1	.....	...	0.861	7.3	.....	...
Dec. 12	.....	...	0.378	2.4	.....	...	.....	...
1902								
Jan. 31	0.530	3.4	[0.605]	[4.0]	0.956	9.0	[1.161]	[14.5]
31	0.503	3.2	0.495	3.1	0.769	5.9	1.056	11.4
	0.508	3.22	0.416	2.61	0.871	7.43	0.807	6.41

1901	WILSING		SCHEINER		WILSING		SCHEINER	
	$\log a_2 \frac{J_1}{J_2}$	$a_2 \frac{J_1}{J_2}$	$\log a_2 \frac{J_1}{J_2}$	$a_2 \frac{J_1}{J_2}$	$\log a_3 \frac{J_1}{J_3}$	$a_3 \frac{J_1}{J_3}$	$\log a_3 \frac{J_1}{J_3}$	$a_3 \frac{J_1}{J_3}$
1901	*Orion* nebula. Trapezium							
Nov. 9	0.468	2.9	0.303	2.0	0.379	2.4	0.451	2.8
Dec. 5	0.528	3.4	.....	...	0.503	3.2	.....	...
5	0.450	2.8	.....	...	0.434	2.7	.....	...
12	.....	...	0.383	2.4	.....	...	0.409	2.6
28	0.461	2.9	0.345	2.2	0.461	2.9	0.408	2.6
1902								
Jan. 31	0.541	3.5	0.463	2.9	0.512	3.3	[0.669]	[4.7]
Feb. 21	[0.644]	[4.4]	0.474	3.0	[0.688]	[4.9]	0.521	3.3
26	0.432	2.7	0.456	2.9	0.417	2.6	0.436	2.7
26	0.399	2.5	0.421	2.6	0.427	2.7	0.306	2.0
28	0.462	2.9	0.366	2.3	0.476	3.0	0.439	2.7
	0.468	2.94	0.401	2.52	0.451	2.83	0.424	2.65
1901	*Orion* nebula. South edge of the Huyghens region							
Dec. 28	0.370	2.3	0.418	2.6	0.390	2.5	0.477	3.0
28	0.410	2.6	0.436	2.7	0.478	3.0	0.519	3.3
1902								
Jan. 31	0.596	3.9	0.352	2.3	0.227	1.7	0.415	2.6
Feb. 21	0.442	2.8	0.459	2.9	0.319	2.1	0.391	2.5
24	0.318	2.1	0.371	2.4	0.181	1.5	0.278	1.9
25	0.557	3.6	0.460	2.9	0.295	2.0	0.395	2.5
25	0.472	3.0	0.451	2.8	0.349	2.2	0.363	2.3
26	0.602	4.0	0.406	2.6	0.364	2.3	0.316	2.1
	0.471	2.96	0.419	2.62	0.325	2.11	0.398	2.50
1902	*Orion* nebula. North edge of the Huyghens region.							
Feb. 21	0.580	3.8	0.479	3.0	0.499	3.2	0.400	2.5
24	0.365	2.3	0.365	2.3	0.317	2.1	0.291	2.0
26	0.588	3.9	0.408	2.6	0.395	2.5	0.370	2.3
28	0.543	3.5	0.420	2.6	0.362	2.3	0.338	2.2
28	0.453	2.8	0.545	3.5	0.395	2.5	0.471	3.0
	0.506	3.21	0.443	2.77	0.394	2.48	0.374	2.37
1902	*Orion* nebula. West edge of the Huyghens region							
Feb. 26	0.282	1.9	0.357	2.3	0.312	2.1	0.524	3.3
28	0.527	3.4	0.478	3.0	0.555	3.6	0.547	3.5
	0.405	2.54	0.418	2.62	0.434	2.72	0.536	3.44

1902	Wilsing		Scheiner		Wilsing		Scheiner	
	$\log a_2 \frac{J_1}{J_2}$	$a_2 \frac{J_1}{J_2}$	$\log a_2 \frac{J_1}{J_2}$	$a_2 \frac{J_1}{J_2}$	$\log a_3 \frac{J_1}{J_3}$	$a_3 \frac{J_1}{J_3}$	$\log a_3 \frac{J_1}{J_3}$	$a_3 \frac{J_1}{J_3}$
1902	*Orion* nebula. Trapezium (40 cm diaphragm).							
Feb. 21	0.471	3.0	0.460	2.9	0.452	2.8	0.460	2.9
21	0.462	2.9	0.434	2.7	0.507	3.2	0.451	2.8
24	0.530	3.4	0.355	2.3	0.521	3.3	0.431	2.7
24	0.583	3.8	0.493	3.1	0.535	3.4	0.349	2.2
	0.512	3.25	0.435	2.72	0.504	3.19	0.423	2.65

The values of this table are now suitable for furnishing the precision of the observations, with general statements of which we shall here content ourselves. The results are as follows for the probable errors, expressed in magnitudes, of the intensity ratios for the mean of an evening, consisting of four settings of the intensity-circle for lines 2 and 3, and eight for line 1. These ratios may be designated briefly as ½ and ⅓.

Observer	½	⅓
Wilsing.............	$\pm 0^m.125$	$\pm 0^m.134$
Scheiner	± 0.105	± 0.152

While the probable errors of the two ratios are nearly the same for Wilsing, that for ⅓ is considerably greater than that for ½ for Scheiner. In the mean the probable errors are nearly the same for the two observers—for Wilsing $\pm 0^m.130$, for Scheiner $\pm 0^m.129$.

It was to be expected that the probable error would come out appreciably larger than for other photometric observations in which the observer on principle does not go below a sufficient brightness. The satisfactory value of the probable error, in spite of this, is to be attributed to the fact that with our relatively large slit-width we were working with appreciable surfaces.

The data of the foregoing table are united into mean values in the following tables A and B, where they are also converted into magnitudes.

TABLE A.

Nebula.	Wilsing		Scheiner		W.–S. in Mag.	Corr. $a_2 \frac{J_1}{J_2}$		Corr. Mag.		Corr. Mean	
	$a_2 \frac{J_1}{J_2}$	Mag.	$a_2 \frac{J_1}{J_2}$	Mag.		W.	S.	W.	S.	$a_2 \frac{J_1}{J_2}$	Mag.
G.C. 4234	2.97	1.16	2.38	0.94	+0.22	2.49	2.32	0.99	0.91	2.40	0.95
G.C. 4373	3.03	1.21	2.59	1.04	+0.17	2.61	2.52	1.04	1.01	2.57	1.03
G.C. 4390	2.65	1.06	2.21	0.86	+0.20	2.27	2.15	0.89	0.83	2.21	0.86
N.G.C. 6790	2.77	1.11	2.24	0.88	+0.23	2.38	2.19	0.94	0.85	2.28	0.90
G.C. 4514	2.64	1.05	2.59	1.03	+0.02	2.25	2.52	0.88	1.00	2.38	0.94
N.G.C. 6891	2.92	1.16	2.55	1.02	+0.14	2.49	2.49	0.99	0.99	2.49	0.99
N.G.C. 7027	3.02	1.20	2.51	1.00	+0.20	2.58	2.45	1.03	0.97	2.51	1.00
G.C. 4964	3.22	1.27	2.61	1.04	+0.23	2.75	2.54	1.10	1.01	2.64	1.06
Orion, Trapezium.	2.94	1.17	2.52	1.00	+0.17	2.51	2.45	1.00	0.97	2.48	0.99
Orion, South	2.96	1.18	2.62	1.05	+0.13	2.54	2.56	1.01	1.02	2.55	1.02
Orion, North	3.21	1.27	2.77	1.11	+0.16	2.75	2.70	1.10	1.08	2.73	1.09
Orion, West	2.54	1.01	2.62	1.05	−0.04	2.17	2.56	0.84	1.02	2.36	0.93
Orion, Tr. (Diaph.)	3.25	1.28	2.72	1.09	+0.19	2.78	2.66	1.11	1.06	2.72	1.09
Mean	2.93	1.16	2.52	1.00	+0.16	2.51	2.45	0.99	0.97	2.49	0.99

TABLE B.

Nebula	Wilsing		Scheiner		Mean		W.–S. in Mag.
	$a_2 \frac{J_1}{J_2}$	Mag.	$a_2 \frac{J_1}{J_2}$	Mag.	$a_2 \frac{J_1}{J_2}$	Mag.	
G.C. 4234	6.43	2.02	5.33	1.82	5.86	1.92	+0.20
G.C. 4373	3.77	1.44	3.62	1.40	3.70	1.42	+0.04
G.C. 4390	4.86	1.72	5.10	1.77	5.02	1.75	−0.05
N.G.C. 6790	8.69	2.35	10.40	2.55	9.55	2.45	−0.20
G.C. 4514	4.47	1.63	4.54	1.64	4.53	1.64	−0.01
N.G.C. 6891	5.45	1.84	6.05	1.96	5.75	1.90	−0.12
N.G.C. 7027	9.62	2.46	8.75	2.36	9.20	2.41	+0.10
G.C. 4964	7.43	2.18	6.41	2.02	6.92	2.10	+0.16
Orion, Trapezium	2.83	1.13	2.65	1.06	2.75	1.10	+0.07
Orion, South	2.11	0.81	2.50	1.00	2.31	0.91	−0.19
Orion, North	2.48	0.99	2.37	0.94	2.44	0.97	+0.05
Orion, West	2.72	1.09	3.44	1.34	3.08	1.22	−0.25
Orion, Tr. (Diaphragm)	3.19	1.26	2.65	1.06	2.91	1.16	+0.20
Mean	4.07	1.53	4.25	1.57	4.17	1.55	−0.04

Now, in the first place, the ratio of the first to the second line (Table A) exhibits an almost absolute constancy in the different nebulæ, so that differences cannot be derived from the nine observed nebulæ. An entirely different behavior is shown

in Table B in respect to the ratio of the first to the third line. Here very pronounced differences from the mean, rising to a magnitude, or to nine times the probable error, occur for both observers, and always in the same sense. It cannot be doubted that at least the larger of these differences are to be considered as real. If we now arrange the nebulæ according to the size of the ratio, we see that the third line is relatively faintest in the small nebula *N.G.C.* 6790, and relatively brightest in the *Orion* nebula, as follows:

N.G.C. 6790	$2^{m}.45$	*G.C.* 4390	$1^{m}.75$
N.G.C. 7027	2.41	*G.C.* 4514	1.64
G.C. 4964	2.10	*G.C.* 4373	1.42
G.C. 4234	1.92	*Orion* nebula	1.10
N.G.C. 6891	1.90		

Accordingly we may state this proposition: In the nine nebulæ we have investigated the ratio of brightness is constant between the first and second lines, but strongly varies between the first and third lines.

This is precisely the result reached by Keeler from his estimates of brightness, which is now confirmed by our measures. We call attention to the fact that this result is favorable to the view that the first and second nebular lines belong to the same element, at present still unknown, and that the hydrogen does not shine in the different nebulæ under the same physical conditions (relative quantity?). The often expressed view, recently again advanced by M. Bélopolsky, that the first and second nebular lines belong to a modified hydrogen spectrum is less favored by our result, although not contradicted by it.

The final means of Table B agree for the two observers within the probable errors, so that there is no constant difference between our measures. It is, therefore, the more surprising that the means in Table A show a clearly pronounced difference, Wilsing–Scheiner $= +0^{m}.17$, although the measured difference of brightness of $\frac{1}{2}$ is considerably smaller than $\frac{1}{3}$. Now, the only difference between the measures of $\frac{1}{2}$ and $\frac{1}{3}$ consisted in the fact that line 1 remained visible in the field while the settings were being made on line 2, which was not the case for settings on

line 3; whence we must infer that the cause of the constant difference lies here. We therefore subsequently investigated this matter with ratios of brightness of $0^m.8$ and $3^m.1$ between the first and second nebular lines, which were artificially produced. The numerous measures do not reveal a dependence on the absolute intensities, but do indicate a marked effect on the settings on line 2 due to the visibility of line 1. This effect was:

For $\frac{1}{2} = 0^m.8$		For $\frac{1}{2} = 3^m.1$	
W.	S.	W.	S.
$-0^m.125$	$-0^m.08$	$-0^m.342$	$-0^m.165$

There is, therefore, a marked increase of the influence with rise of the intensity-ratio. If we interpolate from the above values for the correct ratio for $\frac{1}{2}$, we obtain for the correction, by which the ratio found for $\frac{1}{2}$ is to be diminished,

for W. $-0^m.17$, for S. $-0^m.03$.

The personal difference W.-S. comes out $+0^m.14$, in good agreement with that deduced from the nebular observations. The values corrected in this way for the ratio $\frac{1}{2}$ are given in the last column of Table A, headed "Corr. Mean."

We now believe the mean values given in Tables A and B for the separate nebulæ are free from personal or physiological errors, when compared only among themselves for the elimination of a_2 and a_3. For the ratio $\frac{1}{2}$ it is sufficient to remark that it is to be regarded, from our observations, as constant for the different nebulæ.

If we call the ratio of brightness between the third and first lines in the *Orion* nebula (trapezium) 1, we get for the other nebulæ the following values, which may be compared with similar observations in future, for the purpose of establishing the fact of any changes, or to dispose of them as improbable.

Orion nebula (trapezium)	1.00	*N.G.G.* 4234	0.47
G.C. 4373	0.75	*G.C.* 4964	0.40
G.C. 4514	0.61	*N.G.C.* 7027	0.30
G.C. 4390	0.55	*N.G.C.* 6790	0.29
N.G.C. 6891	0.48		

With these numbers our problem may be regarded as solved, but it is naturally interesting to examine more closely the ques-

tion of the actual ratios of brightness of the three lines among themselves, in order also to obtain the values of a_2 and a_3. The rigorous solution of this problem is possible only with the help of the bolometer, by which the true energy-ratios at the proper places in the spectrum of the photometer lamp could be found. The determination of the "physiological" values of a_2 and a_3 is necessary for obtaining the physiological intensity-ratio of the lines, as it has entered into previous estimates.

As a mean for the two observers, the physiological intensity-ratio of the first to the second line came out as $0^m.5$, and for the first to the third line as $1^m.5$. Hence to us the ratio of the first to the second line would be as 4 : 1 ($1^m.5$) for all nebulæ, while the ratios for the first to the third lines would appear to us as follows in the different nebulæ:

Nebula	1/3
N.G.C. 6790........	40 : 1 ($4^m.0$)
N.G.C. 7027........	36 : 1 (3.9)
G.C. 4964........	27 : 1 (3.6)
G.C. 4234........	23 : 1 (3.4)
N.G.C. 6891........	23 : 1 (3.4)
G.C. 4390........	21 : 1 (3.3)
G.C. 4514........	17 : 1 (3.1)
G.C. 4373........	15 : 1 (2.9)
Orion (trapezium)...	11 : 1 (2.6)

We had the intention of settling by measures on the *Orion* nebula the question whether the intensity-ratio of the nebular lines is the same or different at different parts of the nebula. The question attracted especial attention a few years ago, and we add the following remarks to recall the circumstances. Huggins could not reach a positive opinion, while Vogel expressly remarked that the ratio of brightness of the lines was the same in all parts of the nebula. Keeler also arrived at the same result, but later he adopted the view of Campbell, who had found marked differences, especially near the star *Bond* No. 734 (*Scheiner* No. 260).

One of us (Scheiner) reached conclusions, from observations made in a modified manner, confirming the view originally expressed by Vogel, and he sought to explain the divergent

result of the American astronomers as an effect of the Purkinje phenomenon, since the observers concerned agreed in estimating the third line relatively brighter in the faintest parts of the nebula.

We have hitherto been unable to carry out our intention, as the light-power of the large spectro-photometer is not sufficient to allow lines even to be seen outside the Huyghens region. But in order to make at least a beginning in this direction, we made measures at the edges of the Huyghens region. We went so far that the second and third lines could only just be seen, and the measures could be made only with averted vision. For better exposition we now give a summary of the differences of the ratios between the Huyghens region near the trapezium and near the edges, in the sense trapezium — edges.

	Wilsing		Scheiner		
	$1/2$	$1/3$	$1/2$	$1/3$	Weight
South edge........	$-0^m.01$	$+0^m.32$	$-0^m.05$	$+0^m.06$	8
North edge........	-0.10	$+0.14$	-0.11	$+0.12$	5
West edge.........	$+0.16$	$+0.04$	-0.05	-0.28	2

In the mean for the three edges the third line was measured brighter than for the trapezium — $0^m.22$ by Wilsing, $0^m.04$ by Scheiner. The table shows an evident agreement in the sign, which is essentially negative for $1/2$, and positive for $1/3$. Since we have been able to establish the probability that the ratio $1/2$ is everywhere constant, we must conclude that this agreement in sign is wholly accidental, especially in view of the small numbers in $1/2$.

The same conclusion must therefore be drawn as to the agreement in sign for $1/3$, and hence differences in the intensity-ratios within the Huyghens region are not to be inferred from our measures.

In order to decide whether the intensity-ratio of the lines depends in our measures upon the absolute intensity, we made a few measures in the neighborhood of the trapezium with the

objective stopped down by one-half. These yield the following differences, in the sense full aperture—half aperture:

Wilsing		Scheiner	
½	⅓	½	⅓
$-0^m.09$	$-0^m.00$	$-0^m.11$	$-0^m.13$

They therefore agree with the other measures within the limits of accuracy.

As was mentioned in the beginning, we have by the reduction to the benzine lamp rendered possible the expression in absolute measure of the brightness of the lines for the separate nebulæ, which therefore become mutually comparable. We have here the choice of taking the values for the brightest line or for the sum of the three lines. The latter plan would more nearly approach the ratio of the total brightnesses of the nebulæ, and would in that respect be preferable. But against this we have the fact that the influence of that part of the nebular light which produces the continuous spectrum is eliminated in spectro-photometric measures, while it enters with its full amount into the ordinary photometric measures. We therefore decided to employ only the relative brightness of the first line, and thus give homogeneous results. Calling the brightness of the first line in the brightest nebula 1.00, we get the following magnitudes for the nine nebulæ:

Nebula	W.	S.	Mean	W.-S.
G.C. 4390....	$1^m.00$	$1^m.00$	$1^m.00$	$0^m.00$
N.G.C. 7027....	1.85	1.88	1.87	−0.03
G.C. 4234....	1.88	2.25	2.07	−0.37
G.C. 4373....	2.21	2.40	2.31	−0.19
G.C. 4964....	2.60	2.76	2.68	−0.16
N.G.C. 6790....	2.86	2.59	2.73	+0.27
Orion(trapezium)	3.39	3.13	3.26	+0.26
G.C. 4514....	3.38	3.55	3.47	−0.17
N.G.C. 6891....	3.79	4.01	3.90	−0.22

The probable error of the mean for an evening is $\pm 0\overset{m}{.}21$ for Wilsing, and $\pm 0\overset{m}{.}23$ for Scheiner, which seems very satisfactory in view of the unfavorable circumstances. The agreement between the two observers is also surprisingly good and can be explained only by supposing that the effect of the different conditions of the seeing was almost always in the same sense for the two observers.

POTSDAM, October 1902.

NOTE ON THE WAVE-LENGTH OF THE MAGNESIUM LINE AT λ 4481.

By Henry Crew.

The prominence of this line in the spectra of many stars, notably those of the first class, and possibly those of the solar type, as well as the suggestion of Scheiner[1] that it might be employed as a criterion of stellar temperatures, makes its wave-length a matter of some interest to astrophysicists. I have, therefore, at the request of Professor E. B. Frost, measured the wave-length of this line as it appears in the metallic arc with a rotating electrode.

It will be remembered that the line does not appear in the ordinary arc or flame spectrum of magnesium. And, indeed, it appears in the rotating arc only when a comparatively large current is employed. If a current much less than two amperes for each contact between the fixed and rotating electrodes is employed, no trace of λ 4481 appears, and the spectrum is precisely that obtained with the carbon arc. Thus, if a cross of four equal arms is employed as a rotating electrode, a current of eight amperes is necessary to produce the line in question. If only one contact is used, two amperes will give the same spectrum, but will require four times the exposure. As is well known, the line is diffuse under all circumstances, and, so far as I am aware, is never reversed.

For purposes of measurement both the first and second orders of a ten-foot concave grating were employed. For purposes of comparison about a dozen of Rowland's standard iron lines and an equal number of Hasselberg's cobalt lines were selected. The values obtained are given in the following table. Each value is the result of three settings. It will be observed at once that the discrepancies are enormous when compared with those which would occur, under the same conditions, in the measurement of a moderately sharp line:

[1] Scheiner, *Sitzungsberichte der k. preuss. Akad. Wiss.*, March 1894; translated in *Astronomy and Astro-Physics*, **13**, 569–71, 1894.

Number of Negative	Wave-length in Arc with Rotating Electrode	Wave-length in Spark of "Hedge-hog" Transformer	Remarks
211	4481.326		Negative made seven years ago.
478	.272		
484	.325		
484	.337		Measured by Mr. F. J. Truby.
498 (*a*)	.277		Arc working in an atmosphere of coal gas.
498 (*a*)	.293		Plate measured by Mr. A. A. Knowlton.
498 (*a*)	.260		Plate measured by Mr. A. A. Knowlton.
498 (*b*)	.318		Arc in air, on same plate.
503	.384		Cobalt used for comparison.
505	.390		Cobalt used for comparison.
506	.380		*Ca* and *Ba* in carbon arc used for comparison.
487		4481.364	
492 (*a*)		.302	
492 (*b*)		.256	
Mean	4481.324	4481.306	

It should perhaps be added that the comparison spectrum was put on each of these negatives by making half the exposure before, and half after, the magnesium exposure, the method now usually employed to detect any displacement of the instrument during exposure.

Scheiner[1] has measured this wave-length in eighteen stars of the first class and in eight stars of the second class, from which he derives the definitive value, 4481.52 (Potsdam scale) = 4481.43 (Rowland scale).

Adams[2] has measured fifteen plates taken from three stars in which this line is "sharp, narrow, and of great brilliancy." His result, after elimination of radial velocities, is 4481.400. As to the identity of this line, one is tempted to think that possibly the stellar line is the titanium line at λ 4481.438. But this possibility is practically disposed of by the following extract from a letter of Professor Frost:

It (the stellar line) cannot be the *Ti* line at λ 4481.438 which I constantly use as a comparison line, for that *Ti* line is not at all unusual in its behavior

[1] *Publicationen des Astrophysikalischen Obs. Potsdam*, VII, Th. II, pp. 315, 316.

[2] ASTROPHYSICAL JOURNAL, **15**, 214–17, 1902.

in the arc and spark; and besides, the star line is very strong in stars otherwise showing no *Ti* lines.

Even if we assign the discrepancy in wave-lengths to errors in measurement of the arc line, as is probably the fact of the case, an interesting problem still remains, namely, *to discover the laboratory conditions under which Mg.* 4481 *becomes a sharp line, as in stellar spectra.*

NORTHWESTERN UNIVERSITY,
Evanston, Ill., November 10, 1892.

MINOR CONTRIBUTIONS AND NOTES.

PHOTOGRAPHS AND MEASURES OF THE NEBULA SURROUNDING *NOVA PERSEI*.[1]

THE following negatives of *Nova Persei* have been obtained with the Crossley reflector since those described in *Lick Observatory Bulletin* No. 14.

No.	Date 1902	P. S. T. of Exposure	Duration of Exposure
8	January 31	$6^h\ 46^m$ to $11^h\ 46^m$	$9^h\ 45^m$
	February 2	7 5 " 11 50	
9	March 4	7 21 " 9 50	4 15
	" 6	8 30 " 10 16	
10	" 28	7 43 " 9 15	4 20
	" 29	7 42 " 8 53	
	" 30	7 42 " 9 19	
11	July 12	14 27 " 15 30	5 37
	" 13	14 14 " 15 30	
	" 14	13 54 " 15 31	
	" 15	13 49 " 15 30	

Negatives Nos. 9 and 10 were obtained under very poor conditions. The sky was hazy part of the time, and in some cases the exposure was entirely stopped by clouds. The effective exposure is, therefore, much less than is indicated by the times.

THE NEGATIVES.

No. 8.—Although the seeing on January 31 was poor and the star images not sharp in consequence, this plate shows the nebulosity very satisfactorily. Condensation *D* is considerably brighter than any other portion of the nebula, and I think it is brighter than it was in November and December. There appears to be little, if any, motion radially outward in its central portion where it is brightest, but the northwestern and southeastern wings show an apparent growth. Condensation *A* has undergone considerable change of form, and has continued its outward movement. The outer wisps of nebulosity, *E* and *F*, have undergone the greatest changes. The movements and increase in brightness of both masses, previously pointed out, continue. At this time both condensations are well marked. Excepting condensations

[1] *Lick Observatory, University of California, Bulletin* No. 23.

D and *A*, *E* is now the most conspicuous, being almost as bright as *A*. The structure of mass *F* has become more complicated. It consists of several short wisps approximately in the form of arcs of circles. The *Nova* has faded perceptibly in the interval of three weeks since the last photograph.

No. 9.—The *Nova* has decreased in brightness, and is only slightly brighter than the ninth magnitude star north preceding. There is but little diffused light about the image of the *Nova*, and some small faint masses of nebulosity can be seen to the south of it. Condensation *D* is almost as distinct as on the first plate in November, although the latter had a much greater effective exposure. Condensation *A* is faint but visible. It has become much more pointed, and has increased in size.

No. 10.—The decrease of light in the *Nova* continues, and the image is almost exactly the same size as that of the ninth magnitude star near by. The small masses of nebulosity to the south noted on the previous negative, closer than *D*, are also visible on this plate. Condensation *D* is fully as bright as on the previous plate. Condensation *A* has grown sharper, and but little fainter.

No. 11.—Although obtained under fair conditions of sky and seeing, this exposure of five and one-half hours does not show so much nebulosity as was to be expected. Little, if any, greater density is shown than on negatives Nos. 9 and 10. Condensation *D* is more dense than any other of the masses Just outside of the southwest wing of this condensation is a mass (*Y*) which, in the interval of 107 days since the last photograph, has moved out so as to be seen well separated from *D*. This new mass is nearly as bright as *D*. It gave some indications of its presence in the photographs of March. It is curved about the *Nova*, but not quite circularly, and extends over an arc of some 60°.

Condensation *A* still continues its rapid motion outward, and shows additional changes of structure. It is now much fainter than formerly. The *Nova* has decreased in brightness and is probably a half magnitude fainter than the 9.0 magnitude star near it.

With the fading of the *Nova* and the diffuse nebulosity about it, some appearances have become noticeable which were not so evident earlier. The outlines of condensation *D* are much more clearly marked, especially on the side nearest the *Nova*. Its appearance is strikingly suggestive of jets such as are to be seen in all very bright comets. Very faint extensions can be traced from both wings of the principal mass, one extending to the north and curving about the

PLATE XI.

March 9, 1901. Exposure 10 m.

THE NEBULOSITY AROUND *NOVA PERSEI.*

From negatives made with the Crossley Reflector of the Lick Observatory November 7 and 8, 1901. Exposure 7 h. 19 m.

Nova; the other extending toward the southeast in the direction of condensation *A*. In fact, a faint band of nebulosity can be traced from *D* entirely to *A*.

On this negative nothing can be seen of any of the outer wisps of nebulosity. Some of these may possibly be disclosed by copying the negative on slow plates — which has not yet been done.

On the negatives secured early in January there is a slender ray extending $1\frac{1}{2}'$ to the northeast from the *Nova*. On those plates it does not differ markedly from one of the diffraction rays from the star (due to the supports of the secondary mirror) except that it is broadened about midway, giving it a slightly arrow-headed appearance. As the star faded, however, and the diffraction rays grew less prominent, this ray became more conspicuous. The plates Nos. 9 and 10 show almost no diffraction rays and yet this appendage is there, apparently unchanged in brightness or position. The inner portion on these later negatives is very faint, or wanting entirely, leaving the outer portion almost an isolated mass. As there is no such appendage to the ninth magnitude star near by, this object must be real. The photograph of July 12–15 shows it in the same place, as an isolated mass, and with some structure.

Mr. H. K. Palmer and Mr. R. H. Curtiss, Fellows in Astronomy at the Lick Observatory, rendered efficient assistance in taking the photographs.

THE MEASURES.

Negatives made from the originals by successive copyings were used in making the measures in all cases except the last. The original negative of No. 11 was measured. The nebulosity being too faint to permit of magnification, the points to be measured were indicated on the back of the plate by some definite marks before placing it under the microscope. These marks could be measured very accurately, the settings seldom showing a range of $1''$; and the uncertainty lies in the determination of the proper point for the mark. The changes of form and appearance in the nebulosity render this very difficult, and the resulting positions are therefore subject to a large probable error. In some of the fainter and more poorly defined masses this uncertainty may amount to $10''$ or more. The later negatives, with their much shorter exposure, fail to extend the nebulosity as far as the earlier negatives, and thus, in such cases as the extremities of masses, the points selected are hardly comparable.

Table I contains the measurements of the negative of 1901 March 29. As the appearance of the nebula was so very different at this time from its appearance on the later photographs, no connection with the later series could be traced between the various condensations. A sufficient number of points was chosen arbitrarily in the two rings of nebulosity to represent fairly their forms and dimensions.

Table II contains the position angles of the various condensations, from November 7, 1901, to July 12, 1902.

Table III contains the distances, in seconds of arc, from the same plates.

Table IV contains the results of the measures of the axes of the outer area of the nebulosity on the plates which showed it sufficiently well. On the copied negatives used for measuring, the outlines of this area could be recognized fairly well by looking at the plates from a distance, and by the device of inclining the plate at a considerable angle with the normal to the line of sight. On only one plate could the outlines be traced to the north.

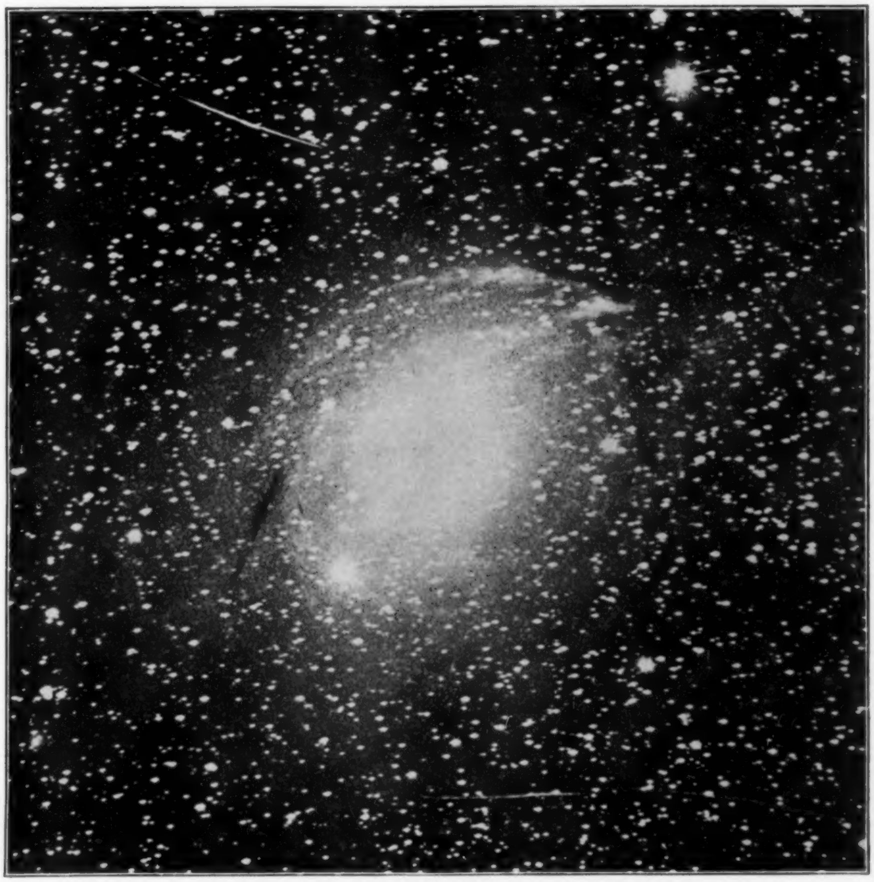
The extreme faintness of this nebulosity and the consequent uncertainty of the measures preclude the drawing of any certain conclusions from so short an interval as to whether the whole of this nebulosity is also expanding. However, the means of the results from these six plates can be considered to give a fairly correct idea of its general form and dimensions. It will be noticed that the area is an ellipse with the *Nova* near the southeast focus. The positions of the axes agree very closely with those of the outer ring of nebulosity on the plate of 1901 March 29.

The measures are referred to the *Nova*.

TABLE I.

Date	Inner ring		Outer ring		Arc to N. E.		Mass to S.	
	p	*s*	*p*	*s*	*p*	*s*	*p*	*s*
1901 March 29	25°.0	83″	1°.0	145″	6°.5	310″	171°.5	160″
	61.8	89	45.3	140	59.6	321	....	
	93.6	81	89.6	140	....		....	
	134.0	64	128.8	149	....		....	
	178.4	67	179.5	102	....		....	
	215.7	45	211.1	101	....		....	
	258.0	69	260.6	133	....		....	
	298.9	69	285.1	147	....		....	
	338.8	76	320.2	144	....		....	

PLATE XII.



THE NEBULOSITY AROUND *NOVA PERSEI.*

From a negative made with the Crossley Reflector of the Lick Observatory on November 12 and 13, 1901. Exposure 10 h.

TABLE II.

Condensation	1901				1902					
	Nov. 7-8	Nov. 12-13	Dec. 4	Dec. 8-11	Jan. 2-3	Jan. 10-11	Jan. 31 Feb. 2	Mar. 4-6	Mar. 28-30	July 12-15
A_1	124°.1	124°.2	124°.0	124°.4	123°.1	122°.9	123°.0	121°.8	120°.7	.....
2	131.0	130.2	129.5	128.8	127.2	127.1	126.5	125.8	124.5	122°.8
3	133.6	133.6	133.1	132.2	130.4	130.7	131.0	129.2	.....	.....
B_1	155.6	155.6	153.5	152.6	149.8	149.5	147.1	.....	141.1	.....
2	162.7	163.8	162.9	160.8	156.8	155.8	153.4	.....	148.9	.....
C	192.6	192.6	188.3	187.1	(203.7)	.....	.....	.....	.....	.....
D_1	156.6	151.2	157.4	159.3	163.6	161.2	164.9	166.2	172.0	154.9
2	214.6	211.3	210.8	212.4	210.5	215.8	216.0	211.4	214.8	183.7
3	263.3	262.0	260.2	268.1	265.5	272.5	275.3	265.4	268.0	270.3
E_1	.....	.....	211.9	210.8	223.8	223.8	224.8	233.2	.....	.....
2	.....	.....	.....	.....	.....	223.3	.....	.....	.....	.....
F_1	.....	344.4	.....	350.3	343.8	345.0	341.7	.....	.....	.....
2	.....	351.0	.....	356.6	347.6	346.1	342.4	.....	.....	.....
3	.....	.....	.....	359.5	351.2	351.2	345.9	.....	.....	.....
4	.....	.....	.....	5.3	353.6	352.8	349.7	.....	.....	.....
5	.....	.....	.....	.....	359.3	359.2	353.3	.....	.....	.....
6	.....	.....	.....	.....	.....	.....	355.6	.....	.....	.....
G	272.5	270.7	271.4	271.6	275.5	278.4	276.0	.....	.....	.....
H	279.3	281.1	285.7	277.3	284.6	285.6	284.6	.....	.....	.....
I	358.0	1.0	358.4	355.7	353.8	352.6	353.0	347.5	.....	.....
J	120.4	119.4	117.4	119.5	119.2	120.3	120.2	119.0	.....	.....
K	137.4	149.1	.....	.....	.....	134.8	.....	.....	.....	.....
L	172.8	182.4	174.6	168.3	189.4	180.9	180.6	.....	.....	.....
M	244.5	242.1	244.2	244.0	251.1	259.2	248.6	.....	.....	.....
N	305.3	305.0	305.2	304.5	303.5	307.8	306.6	.....	.....	.....
O	.....	.....	.....	290.4	297.3	293.4	295.0	.....	.....	.....
P	.....	.....	.....	.....	.....	245.3	.....	.....	.....	.....
Q	.....	.....	.....	.....	32.4	32.7	29.8	31.8	30.7	32.4
R	.....	.....	.....	.....	.....	62.2	66.8	.....	.....	.....
S	.....	.....	.....	.....	.....	343.0	341.5	.....	.....	.....
T_1	.....	.....	142.1	138.0	133.3	133.4	132.6	130.2	128.6	.....
2	.....	.....	.....	.....	140.0	142.7	139.9	133.6	.....	.....
U	.....	.....	.....	.....	.....	.....	329.7	.....	.....	.....
V	.....	.....	.....	.....	.....	261.0	.....	.....	.....	.....
W	.....	.....	.....	.....	.....	.....	337.8	.....	.....	.....
X	.....	.....	.....	.....	.....	.....	12.0	.....	.....	.....
Y	.....	.....	.....	.....	.....	.....	.....	.....	.....	141.2

TABLE III.

Condensation	1901				1902					
	Nov. 7-8	Nov. 12-13	Dec. 4	Dec. 8-11	Jan. 2-3	Jan. 10-11	Jan. 31 Feb. 2	Mar. 4-6	Mar. 28-30	July 12-15
A_1	531″	532″	559″	579″	587″	634″	644″	650″	699″	....
$_2$	480	485	508	519	535	553	575	583	625	722″
$_3$	412	413	427	437	470	485	483	500	....	....
B_1	415	432	425	439	453	458	497	....	556	....
$_2$	397	395	410	427	442	449	475	....	518	....
C	371	375	414	414	(439)	....	....	....	....	....
D_1	130	133	129	149	150	150	153	143	137	169
$_2$	100	90	92	102	105	97	103	101	99	104
$_3$	175	168	180	205	201	210	213	209	212	241
E_1	....	....	818	808	839	845	866	890	....	....
$_2$	....	....	....	....	....	792	....	....	....	....
F_1	....	873	....	921	895	920	981	....	....	....
$_2$	....	813	....	937	947	961	938	....	....	....
$_3$	....	....	....	894	912	928	947	....	....	....
$_4$	....	....	....	959	973	981	973	....	....	....
$_5$	....	....	....	....	942	957	962	....	....	....
$_6$	....	....	....	....	....	....	815	....	....	....
G	441	424	437	470	499	513	506	....	....	....
H	293	294	363	327	379	395	401	....	....	....
I	388	387	395	410	428	431	444	466	....	....
J	432	439	441	462	487	493	516	536	....	....
K	333	294	....	....	....	410	....	....	....	....
L	248	233	248	279	274	282	303	....	....	....
M	390	383	388	415	421	457	450	....	....	....
N	374	422	425	450	450	479	495	....	....	....
O	....	....	....	225	251	245	258	....	....	....
P	....	....	....	....	....	368	....	....	....	....
Q	....	....	....	....	90	142	88	102	99	112
R	....	....	....	....	....	439	433	....	....	....
S	....	....	....	....	....	571	589	....	....	....
T_1	....	....	420	447	503	516	536	572	588	....
$_2$	....	....	....	....	436	449	471	528	....	....
U	....	....	....	....	....	....	1034	....	....	....
V	....	....	....	....	....	833	....	....	....	....
W	....	....	....	....	....	....	442	....	....	....
X	....	....	....	....	....	....	1057	....	....	....
Y	....	....	....	....	....	....	....	....	....	190

PLATE XIII.

THE NEBULOSITY AROUND *NOVA PERSEI.*

From a negative made with the Crossley Reflector of the Lick Observatory on December 8 and 11, 1901. Exposure 10 h.

TABLE IV.

Date	Major axis				Minor axis			
1901	*p*	*s*	*p*	*s*	*p*	*s*	*p*	*s*
November 7–8.....	99°	1007″	279°	1239″	197°	821″	...	...
12–13.....	106	981	286	1162	198	860	13°	870″
December 8–11.....	122	1079	297	1015	209	808	...	...
1902								
January 2–3.....	118	1108	300	1022	210	849	...	...
10–11.....	124	1044	307	1185	214	914	...	...
Jan. 31–Feb. 2.....	121	1064	299	1267	206	894	...	...
Mean..........	115	1047	295	1148	207	858	...	...

Condensation *A* is the only one of those showing large motion which has retained its form throughout the series of observations sufficiently to enable a good determination of its motion to be made. The positions of the brightest and best defined portion of this mass (A_2) were plotted on a large scale. A straight line, in position angle 107°.5, seems to represent the direction of motion best. During the interval of 255 days, between November 7, 1901, and July 13, 1902, the displacement amounts to 258″, almost exactly 1″ per day. Projecting this point backward, we find that on February 17, 1901, its position would be, position angle 154°.0, and distance 252″. This does not indicate coincidence at the time of the outburst either with condensation *D*, or with the mass of nebulosity to the south of the rings on the negative of March 29, 1901.

FAINT STARS NEAR THE *NOVA*.

The long-exposure negatives show a number of faint stars near the *Nova*. Although the images are not perfect enough for any great accuracy of measurement, I have thought that it might be useful to give the coördinates of all within 1′ of the *Nova*, especially as most of them are not included in the charts and measures published by Aitken[1] and Barnard.[2] The results given in the accompanying table were obtained from measures of the plate of July 12–15, 1902. As the refraction corrections are less than the uncertainties of the measures they have not been applied. The magnitudes of the stars *l*, *m*, *n*, and *p*, were observed visually, and have been adopted in the table. The magnitudes of the others are based upon these.

[1] *Lick Observatory Bulletin*, No. 8.

[2] *Astronomische Nachrichten*, 159, 50, 1902.

The position of star *l* as obtained from the photograph does not agree with that given by Aitken. It has also been measured on the plate of March 4–6. The agreement between the positions from the two plates is as close as can be expected from the character of the images, and gives no certain indication of a change of position.

FAINT STARS NEAR *NOVA PERSEI.*

Star	*p*	*s*	Magnitude
a	31°.5	57′.2	15
b	32.2	48.0	18
c	32.2	33.9	16
d	67.6	61.5	18
e	68.4	19.5	15
f	78.9	63.4	18
g	148.8	51.3	17
h	224.5	42.0	16
i	265.6	45.4	18
j	290.7	19.6	18
k	300.9	14.2	18
l	338.5	45.6	16.5
(*l*)[1]	(337.9)	(47.1)	....
m	57.0	132.5	13.9
n	107.4	91.1	13.5
o	236.2	103.5	15
p	303.6	163.8	13.1

THE ILLUSTRATIONS.[2]

The plates accompanying this *Bulletin* are direct photographic reproductions from negatives, and are enlarged 2¼ diameters. The scale of the plates is 17″ to the millimeter. The negatives were obtained by successive copyings of the originals on slow plates.

The top of each plate is south.

There are several scratches in the glass of the original negatives which appear on the printed plates. One small one is to be seen on the plate of March 29, and two large ones on that of November 12–13.

The faint outer nebulosity is well shown, considering its elusive character, on several of the plates. The later plates show the appearance and growth of the wisps *E* and *F* near the outer edges of this region, to the southwest and north, respectively, of the Nova. The form of the bright inner mass *D* is best shown on the plate of January 10–11.

[1] Plate of March 4–6, 1902, for comparison.

[2] The original electrotypes have been kindly loaned by Professor Campbell for reproduction in this JOURNAL.

PLATE XIV.

THE NEBULOSITY AROUND *NOVA PERSEI.*

From a negative made with the Crossley Reflector of the Lick Observatory on January 10 and 11, 1902. Exposure 10 h. 30 m.

OBSERVATIONS OF THE NEBULOSITY ABOUT *NOVA PERSEI* FOR POLARIZATION EFFECTS.

THE interpretation of the changes observed in the nebulosity surrounding *Nova Persei* would be much facilitated by spectroscopic or other physical observations. On account of the faintness of the nebulosity, spectroscopic investigations held out little hope of definite results, but the possibility of detecting polarization effects suggested itself. The success of the Crocker Expedition in detecting polarization in the light of the corona at the Sumatra eclipse strengthened the probability that such a method would be efficient in the case of the nebula. The conditions seemed even more favorable in the case of the nebula where the plane of polarization should be better defined than in the corona.

To this end a double-image prism was placed in the optical axis of the Crossley reflector, between the diagonal mirror and the plate. It was mounted in an auxiliary frame to permit its being set in all position angles. Following are the constants of the double-image prism and its position in the telescope:

Clear aperture	33 mm
Thickness of prism	23
Distance from the film of dry plate to the nearest surface of prism	66
Separation of images	6

The interposition of this prism was found to lengthen the focus of the telescope 10 mm.

The star images were considerably elongated by the prism in the direction of its principal plane. The field of the prism was sufficiently large to include the Nova and condensations *A* and *D*. The principal plane was made to pass through the *Nova* and *A*. As the plane passing through the *Nova* and *D* was at right angles to that passing through *A*, this position of the prism sufficed to test *D* also.

It is well known that there is but little effect produced upon polarized light by reflecting it from metallic surfaces. In the case of the parabolic mirror (silver on glass) there is practically no effect, as the reflection is so nearly normal. The diagonal plane mirror of the Newtonian form, however, has a small effect if the plane of polarization is not parallel (or perpendicular) to the plane of reflection of the diagonal. The mounting of the Crossley reflector is such that it was not possible to place these planes in the most favorable position without

reducing the exposure times at that season of the year so seriously as to endanger the securing of any results whatever. The eye-end of the telescope was used in a position, therefore, in which these planes made an angle of 45° with each other.

With this arrangement of telescope and prism a negative of the *Nova* was secured with the following exposures:

March 10 - - - - - - - - - - - -	$3^h\ 8^m$
11 - - - - - - - - - - - -	2 57
12 - - - - - - - - - - - -	1 22
Total exposure - - - - - -	$7^h\ 27^m$

The conditions were not good at any time, and on the last night clouds interfered seriously. The star images on the resulting negative are poor, owing to the causes mentioned. The negative shows the two condensations *A* and *D*. The other condensations were too faint to make any impression. Both images of *D* are very distinct, and there seems to be no appreciable difference of intensity. The images of *A* are both extremely faint. One of them is in the overlapping fields given by the prism where the film is considerably darkened by diffused light from the sky. The other image is in a region where only one beam from the prism fell upon the plate, and where the darkening of the film is much less. It is therefore much more difficult to judge of the relative intensities of these images. Allowing for these variations as well as possible, these two images appear to be of the same intensity.

After this photograph had been taken a method occurred to me of testing the effect of the mirrors — particularly the diagonal — upon polarized light. This was to pass polarized light through the telescope, and observe it with the double-image prism.

The plane unsilvered mirror of our heliostat was placed in front of the telescope in such a position that the light of a star was reflected from it into the telescope at the angle of maximum polarization (approximately 56° for flint glass). The light to be observed was, therefore, almost totally polarized. All other light was carefully excluded.

The heliostat mirror was only $7\frac{1}{2}$ inches in diameter, but sufficient light was obtained by observing a first or second magnitude star. The plane of reflection of the diagonal was placed successively parallel to, at an angle of approximately 45° with, and perpendicular to the plane of polarization, and the effect was observed visually with the double-

PLATE XV.

THE NEBULOSITY AROUND *NOVA PERSEI.*

From a negative made with the Crossley Reflector of the Lick Observatory on January 31 and February 2, 1902. Exposure 9 h. 45 m.

image prism. In the two positions in which the plane of reflection of the diagonal was parallel and perpendicular to the plane of polarization, the extraordinary image could be almost wholly extinguished. When these two planes were at an angle of $45°$ (the position of the prism during the taking of the photograph) there was a depolarizing effect, the extraordinary image being possibly one-tenth the brightness of the ordinary image. α *Lyrae* was the source of light employed. These observations of the effect of the telescope upon polarized light enabled a more certain interpretation to be made of the evidence afforded by the photograph of the *Nova*.

The foregoing observations point to little or no polarization effect in the light from condensation *D*, and, with perhaps less certainty, in condensation *A*.

It does not follow that the nebula is not shining by reflected light; but in view of the result from the corona already referred to, we should be led to expect some polarization effects if the light were all or nearly all reflected.

Owing to the very unusual amount of stormy weather, the experiments on the effect on the mirrors upon polarized light were greatly delayed.

It is hoped to repeat these polarization observations, under more favorable conditions, as soon as the *Nova* is again in good position for observing.

An effort will also be made to secure some spectroscopic evidence with a spectrograph which has been designed for the problem.

THE CHARACTER OF THE PHENOMENA OBSERVED IN THE NEBULOSITY SURROUNDING *NOVA PERSEI*.

Several explanations have been advanced to account for the apparent motions observed in the nebula about *Nova Persei*. We shall point out some of the considerations which bear most strongly on the question of the character of these phenomena. The principal results of the observations are as follows:

1. There appear to be two pretty well defined areas of nebulosity: a bright inner ring or disk about $15'$ in diameter; and a very faint outer ring about $30'$ in diameter (January 1902).

2. The inner ring is expanding. Two series of wisps near the outer edge of the outer ring indicate expansion in that ring also. A comparison of photographs made in January, 1902, with a photograph of the *Nova* taken on March 29, 1901, which shows two faint rings of nebulosity, indicates the following daily rates of radial expan-

sion for the circumferences of the two areas, assuming the former to result from the latter:

Inner ring (average) - - - - - - - -	1.4
Outer ring (from two rings) - - - - - -	2.8

The above rates of expansion would carry the inner ring back to the *Nova* on February 8, 1901 (deduced from the plates of March 29, 1901, and January 10–11, 1902). Both plates give the same date. The outer ring would in a similar way be carried back to the *Nova* on February 16 and 17, 1901 (deduced from the plates of March 29, 1901, and January 2–3, 1902). These results do not necessarily imply the earlier formation of the inner ring, but, considering the uncertainties of measurement, they point rather to a contemporary origin.

3. Both rings show considerable structure. Many of the separate condensations have individual motions, which are usually not radial, but contain large tangential components. Clockwise and counter-clockwise motions are found in both rings.

4. The observations made with a double-image prism indicate little or no polarization effects in the two brightest condensations.

5. The inner ring and its condensations have shown a consistent decrease of light. In the outer ring, on the other hand, masses of nebulosity have become visible and have shown rapid increase in brightness, as well as changes of form.

The first explanation that naturally suggests itself is that the observed motions are due to real translations of matter. As far as the velocities alone are concerned, there would appear to be no positive objections to this view, so long as the velocities do not exceed that of light. The exhibitions of force with which we are familiar lead us to expect high velocities in the case of so stupendous an outburst as that of the *Nova*.

There are other objections to this explanation, however. The motions observed are not radial. Nearly all of them have large tangential components. It is difficult to account for these tangential components. A consideration of the conditions probably existing in the nebula, upon the assumption of an actual translation of matter, would lead us to expect a very rapid loss of light.

The inner ring has decreased in brightness, and some of its features have become too faint to record themselves on the photographs. Several masses, all in the outer ring, have been recorded only on the later photographs, and have grown both in brightness and size, a con-

dition difficult to explain on the above hypothesis. It is perhaps not inconceivable that the two rings represent different phenomena.

The idea that the observed phenomena in this nebulosity might be due to light waves seems to have suggested itself about the same time to many persons. It appears to have been first published by Kapteyn.[1]

While several hypotheses are possible, only one seems worth considering, viz., that finely divided solid or gaseous stationary matter, having the observed structure, is illuminated by light waves emanating from the *Nova*. The appearance and growth of the wisps in the outer ring of nebulosity are facts which seem to be well explained by this theory.

An accurate knowledge of the star's parallax would be a strong test of this theory. The assumed velocities of expansion for the outer ring would limit it to $0''.02$. The determinations made so far have generally been negative, indicating that it is small, and therefore not inconsistent with the above theory.

The forms of the two rings of nebulosity and their symmetrical arrangement with respect to the *Nova*, lead us to believe that the displacements of their outer portions are the maximum, and relatively comparable. If this is the case, and the two rings have been formed by the expansion of earlier ones, all of which appear to have emanated from the star about the time of its greatest brilliancy in February 1901, we have two widely different velocities indicated. Such a condition is inconsistent with our present knowledge of light.

As the increase of light in the *Nova* was much more rapid than its decrease, the outer surface of the light wave should be more sharply defined than the inner. There seems to be no evidence of any such difference. It is not quite clear how some of the best marked condensations could retain such distinctive forms and still be displaced, if the streams of matter giving rise to them are normal, or nearly so, to our line of sight, as they appear to be. It would seem also as if some of the condensations were bright enough to leave some trace after the principal wave of light had passed.

The bearing of the polarization observations on the theory of light waves has already been pointed out.

Another explanation is that the light of this nebulosity is inherent and due to incandescence resulting from some form of electrical excitation or other invisible radiations from the *Nova*. As yet there seems to be little direct evidence either for or against such a theory.

[1] *Astronomische Nachrichten*, 157, 201, 1901.

Our conception of the conditions most probably obtaining in such an outburst as that of *Nova Persei* would lead us to expect that the pressure effect shown to exist in heat and light, would be an active factor in producing the observed appearance. There is no evidence, however, of any acceleration in the velocity of condensention *A*, which is the only one sufficiently well observed. The measures indicate a slight retardation in the velocity of this condensation, but the large probable error makes it doubtful if there has been any real change.

C. D. PERRINE.

July 24, 1902.

ON A NEW OBJECTIVE METHOD FOR THE MEASUREMENT OF SPECTROGRAMS.[1]

The method is that used for several years past by Exner and Haschek in their work on the ultra-violet spark spectra of the elements; it was briefly described in *Sitzungsberichte d. k. Akademie zu Wien*, 1895, p. 913.

The spectrum is directly projected on a screen of fine drawing paper by a lantern provided with all the various adjustments necessary. The enlargement of the projected image on the screen may be controlled within narrow limits. The negative is held in a frame, which may be moved longitudinally by hand, vertically by a screw, and may be rotated so as to secure verticality of the projected lines.

The screen is made of fine drawing paper, tightly stretched, with due precautions to avoid warping of its support. Two rods of iron at the top rest upon rollers and permit a smooth movement of the screen as a whole in the direction of its length. Two lower brackets support a slotted bar, in which the lower side of the screen moves while keeping its plane unaltered. Three millimeter scales, of which only the middle one is used, are fastened to the screen at a distance of 30 cm from center to center. A distance of one meter at the center of the screen is all that is used in practice, as at the edges the definition is not so sharp. Reels carry a strip of paper, on which are accurately laid off one thousand standard lines, with their wave-lengths (Rowland). One hundred tenth-meters cover one meter on the screen. This moves so easily that it can be shifted within a tenth of a millimeter without trouble, corresponding to 0.01 tenth-meter. The position of the lines projected on the screen can be read off by estimation to 0.1^{mm}, corre-

[1] Abstract, by Heber D. Curtis, of a paper by Karl Kostersitz.

sponding to 0.01 tenth-meter, as mentioned above. In measurement standard lines are chosen, as close as possible to the lines under consideration, so as to make the measures depend upon a small section of the scale. The screen is then shifted so as to give the correct reading for this line. The proper degree of enlargement has been previously secured. The position of the desired line may be at once read off in Ångström units.

With especially strong or broad lines he used a "thread-shadow micrometer" (*Faden-schaltens Mikrometer*). This is simply a frame, over whose central opening a thread is stretched. This is placed over the line, and its shadow made to coincide with the pointed ends of the lines. The position of the shadow on the central scale is then read off.

Kayser holds that the method is less accurate than a comparator. Kostersitz claims that this contention is borne out neither by the character of the method as such, nor by the results already secured with it. Readings may be made with entire accuracy to 0.01 tenth-meter. To test the accuracy of the method a spectrum was remeasured after an interval of several weeks had elapsed. The mean of the differences, without regard to sign, for 103 lines was 0.013 tenth-meter.

The deviations were grouped as follows:

0.00 tenth-meter in 28 cases
0.01 tenth-meter in 32 cases
0.02 tenth-meter in 30 cases
0.03 tenth-meter in 10 cases
0.04 tenth-meter in 2 cases
0.05 tenth-meter in 1 case

No deviations greater than 0.05 occurred. This was based on a *single* direct reading for each line, not the mean of several. An investigation of 1,531 cases in spectra of various elements gives for the average deviation 0.015 tenth-meter. By the use of plate glass instead of ordinary glass, Exner and Haschek have since reduced this to 0.0127 tenth-meter.

A comparison is also given between the results of Rowland, Kayser, and Exner and Haschek, in measurements of the spectrum of platinum. Δ_1 denotes the mean and Δ_2 the maximum deviation.

	Δ_1	Δ_2
K.—R.	0.010	0.046 tenth-meter
E. H.—R.	0.015	0.044
E. H.—K.	0.014	0.058

The measurements of E. and H. were single, direct readings on the

spark spectrum, those of Kayser are the mean of six readings, on the sharper lines of the arc.

There is a great advantage also in speed, no computations being necessary in the determination of the wave-lengths. In the space of one and a half years the spectra of seventy-five elements were investigated, involving the positions of about 50,000 lines, a task which would have been nearly impossible by ordinary methods.

Among the advantages claimed are :

Quickness and accuracy.

Ease with which spectra may be examined as a whole, impurities and anomalies detected, and elements identified.

Errors in the scale have less effect than those of the micrometer screw ; and may be more easily controlled and allowed for.

Mistakes in scale-reading are less liable to occur than in the readings of a divided micrometer-screw head.

Ease of the observer ; less strain on the eyes.

The elimination, to a considerable extent, of the psychological peculiarities of readings made with microscopes.

The author's rather hopeful claims for the utility of the method in detecting shifts of spectral lines have yet to be proven by trial. The lack of normality of the prism spectrum might be obviated by projecting on a screen, as in the Exner-Haschek method, and enlarging or diminishing the image so as to coincide with a previously computed dispersion. When the comparison lines fell into their proper places on the screen, the positions of the lines of the star spectrum could be rapidly read off and compared with their computed places.

The difficulty caused by the relatively broad and hazy lines, as compared with the beautifully sharp lines of grating spectra, would be the greatest hindrance ; only an actual trial could determine the possibility of accurate results from the Exner-Haschek method with star spectra.

KARL KOSTERSITZ.

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